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PROJECT APOLLO

LUNAR EXCURSION MODULE DEVELOPMENT STATEMENT OF WORK (U)

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JUNE 18, 1962

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TABLE OF CONTENTS

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TABLE OF CONTENTS

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1.0 INTRODUCTION

1.1 Purpose. - The purpose of this document is to describe the tasks required of the Lunar Excursion Module Associate Contractor in the development of the Lunar Excursion Module and to present the technical framework within which these tasks will be performed. This Lunar Excursion Module will be integrated into the Apollo Spacecraft System by the Apollo Principal Contractor.

1.2 Apollo Project Objective. - The objective of the Apollo project is the landing of men on the moon, limited observation and exploration of the moon by the crew in the landing area and return to earth. The Apollo development plan envisages the qualification of the Spacecraft and its Modules in a series of increasingly complex missions proceeding from sub-orbital through circumlunar to the lunar landing mission.

1.3 Mission Technique. - The lunar orbit rendezvous technique will be used to perform the lunar landing mission. Employing this technique, the Spacecraft consisting of the Command Module, Service Module, and Lunar Excursion Module is injected into a translunar trajectory. In lunar orbit the Lunar Excursion Module with two crew members aboard separates from the Command Module and descends to a lunar landing. The third crew member remains in the Command Module in lunar orbit. The Lunar Excursion Module crew performs their mission objective tasks and returns to lunar orbit with records and specimens. The Lunar Excursion Module crew performs a rendezvous and docking maneuver with the Command Module. The crew and payload transfer to the Command Module and the Command Module, with or without the Lunar Excursion Module, is injected into a transearth trajectory by the Service Module propulsion system.

1.4 Major Milestones. - The project milestones including those for the development of the Lunar Excursion Module are presented in Table I.

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2.0 CONTRACTOR'S TASKS. - The Contractor shall be responsible for the design, manufacture, and operations in relation to the Lunar Excursion Module, its Ground Support Equipment, and associated training equipment to the extent stated in the following paragraphs.

2.1 Design. - The design responsibilities of the Contractor are indicated below. The use of Government Furnished Equipment or Industry Standard Equipment shall be investigated and proposed by the Contractor where feasible and practical. The Contractor shall determine and conduct the research and development program required to support his design effort. Where development tests of the complete Spacecraft are required, the Contractor shall support the Principal Contractor. He shall request the participation of NASA or other government facilities where appropriate.

2.1.1 Lunar Excursion Module. - The Contractor shall be responsible for the detail analyses and design of the Lunar Excursion Module prototypes, boilerplates, and mockups with the exception of certain Government Furnished Equipment. The systems and equipment which will be Government Furnished Equipment are the Navigation and Guidance System, Flight Research and Development Instrumentation/Communication System, Scientific Instrumentation System, and Crew Equipment (Pressure Suits, Portable Life Support Equipment, "Shirtsleeve" Garments, Personal Radiation Dosimeters, and Bio-Instrumentation Sensors). The Contractor will be responsible for integrating this Government Furnished Equipment into the Lunar Excursion Module; developing specifications for equipment performance, interfaces, and design environment; and maintaining interface control documentation in a state of validity and concurrence. The Contractor shall utilize the data submitted by the GFE contractors in the performance of this responsibility, e.g., the weight statements of the GFE contractors will be utilized without the Contractor re-estimating the weight of the GFE. The Contractor shall assist NASA in the review of the plans submitted by the GFE contractors. Appendix A presents the technical framework within which the Apollo Spacecraft development shall be implemented including a description of the Lunar Excursion Module, a model mission, environment, and propulsion requirements in terms of velocity requirements. A final design mission will be determined based on the detailed studies conducted. The Contractor's responsibility in the areas of Trajectory Analysis, Environmental Analysis, Repositioning Analysis, and Mission Operational Analysis is further defined in the following paragraphs. The intent of

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these paragraphs is to indicate the scope of the Contractor's interface responsibilities in all areas by these examples.

2.1.1.1 Trajectory Analysis. - The Contractor shall be responsible for detailed trajectory analysis from lunar orbit separation until lunar orbit rendezvous. This shall include studies to optimize the lunar orbit characteristics, position of separation, descent trajectories, abort analysis, ascent trajectories, and positions of rendezvous.

2.1.1.2 Environmental Analysis. - The Contractor shall be responsible for detailing the mission environment on the lunar surface and for assessing the effects of the adapter environment on the Lunar Excursion Module. The Contractor shall also be responsible for the specifications of the design environment for the Lunar Excursion Module GFE.

2.1.1.3 Repositioning Analysis. - The Contractor shall be responsible for the detail design of the Lunar Excursion Module mounted equipment for repositioning and mating the Lunar Excursion Module to the Command Module. This equipment will be designed within the overall specification of the Principal Contractor.

2.1.1.4 Mission Operational Analysis. - The Contractor shall be responsible for determining and proposing the desirability of checkout and/or operation of the Lunar Excursion Module during the translunar period of the flight. This shall include the desirability of crew access to the Lunar Excursion Module from the Command Module during this period. It shall include the determination and proposal of systems support from the Command or Service Module such as power from the fuel cells or oxygen for cooling, breathing, or pressurization and the support required from these Modules while separated during the landing phase of the mission. The Contractor shall determine and propose the crew tasks related to the Lunar Excursion Module prior to separation whether they are actually performed in the Lunar Excursion Module or the Command Module. The Contractor shall be responsible for the determination of the Lunar Excursion Module crew tasks during the separated portion of the flight including the tasks related to the operation of the Lunar Excursion Module GFE. The tasks directly related to lunar exploration while on the lunar surface will not be the responsiblity of the Contractor.

2.1.2 Ground Support Equipment. - The Contractor's responsibility for the design and integration of GSE for any part of the Lunar Excursion Module shall be to the same extent as his responsibility for the design and integration of that part of the Lunar Excursion Module.

2.1.3 Training Equipment.- The Contractor shall be responsible for the design of certain training equipment directly associated with the Lunar Excursion Module for the training of flight and/or ground personnel as required by the NASA.

2.2 Manufacturing.- The Contractor shall be responsible for the manufacture of the Lunar Excursion Module mockups, boilerplates, and prototypes with the exception of the GFE indicated above. The Contractor shall be responsible for the manufacture of the GSE for the equipment which he furnishes and shall also furnish the training equipment required. The Contractor shall install all GFE in the Lunar Excursion Module prior to delivery. The receiving acceptance tests and systems tests of GFE will be conducted by the GFE Contractors at the Contractor's plant under the overall test direction of the Contractor. After these tests are completed, simplified checkout tests may be conducted by the Contractor. If a malfunction occurs or is suspected and additional tests are required, these will be conducted as before by the GFE contractor working with the Contractor. Subsequent to delivery the same procedure will be followed between the various tiers of contractors involved. The quality of all equipment manufactured shall be controlled by a quality control system complying with reference 11.

2.3 Operations.- The Contractor shall support the operations of the Lunar Excursion Module. The Contractor shall perform the prelaunch preparation and checkout of the Lunar Excursion Module working with the other contractors in the same manner as during systems testing. He shall integrate the GFE preparation and checkout and be responsible to the Principal Contractor for coordinating all Lunar Excursion Module activities with the overall Spacecraft prelaunch requirements. The Contractor shall report to the Principal Contractor the preflight status of the Lunar Excursion Module. He shall provide personnel to support the flight operation in ground monitoring of the Lunar Excursion Module Systems and perform post flight analysis of the performance of the various subsystems of the Lunar Excursion Module.

2.4 Reliability.- As an integral part of the design and development program, the Contractor shall implement a reliability program to assure compliance with reliability goals apportioned to the Lunar Excursion Module. The program shall be coordinated with the overall reliability program for the Spacecraft. The Contractor will apportion reliability goals to the GFE contractors and assess and monitor their reliability program and performance.

2.5 Logistics. - The Contractor shall be responsible for providing adequate logistics support for the equipment which he furnishes. Logistics support shall include all spares and transportation.

2.6 Documentation. - The Contractor shall provide the documentation described in Paragraph 4.5. All documents required shall be classified as one of three types. Type I documentation shall be submitted to the NASA for approval. Type II documentation shall not require approval, but shall be submitted for coordintaion, surveillance, and/or information. Type III documentation shall be retained by the Contractor and made available to authorized representatives of the NASA for review, upon request.

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3.0 NASA AND OTHER CONTRACTOR RELATED TASKS.- The Lunar Excursion Module contract will be managed by the Manned Spacecraft Center of the NASA. The development of the Lunar Excursion Module will require contact with the Principal Contractor and to a certain extent with other contractors and government organizations. The NASA will arrange the procedures for, and will monitor these contracts. The following paragraphs define those NASA and/or Principal Contractor tasks related to the Lunar Excursion Module for the purpose of better defining the Lunar Excursion Module Associate Contractor's tasks. NASA's responsibility as used in this document does not preclude parts of the responsibility being carried out through other NASA Contractors.

3.1 Design.- The Principal Contractor will design the Command Module, Service Module, and all adapters and will integrate the Lunar Excursion Module and its associated GSE into the Apollo Spacecraft System. The Principal Contractor will utilize the data submitted by the Contractor in the performance of his integration responsibility, e.g., the weight statements of the Contractor will be utilized without the Contractor re-estimating the weight of the Lunar Excursion Module. He will develop specifications for the interface between the equipment which he provides and the Lunar Excursion Module including the Lunar Excursion Module geometric envelope, attachment points, and all other mechanical and electrical interfaces. The Principal Contractor will assist NASA in the review of the plans submitted by the Contractor. The NASA will be responsible for the detail development of the GFE which will be used in the Lunar Excursion Module. The Principal Contractor's interface responsibilities in the areas of trajectory analysis, environmental analysis, repositioning analysis, and mission operational analysis are indicated below.

3.1.1 Trajectory Analysis.- The Principal Contractor will be responsible for the overall trajectory analysis for the lunar mission excluding the detailed analysis of the Lunar Excursion Module trajectory while separated from the Command and Service Module.

3.1.2 Environmental Analysis.- The Principal Contractor will determine the natural environment for the entire mission with the exception of the environment on the lunar surface and will specify the environment within the adapter which will house the Lunar Excursion Module.

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3.1.3 Repositioning Analysis.- The Principal Contractor will be responsible for the determination of the methods and/or devices to be used in repositioning and mating the Lunar Excursion Module with the Command Module and for the preparation of an overall specification for the associated hardware mounted on the Lunar Excursion Module.

3.1.4 Mission Operational Analysis.- The Principal Contractor will assess and integrate the support required from the Command and Service Modules and from the crew during the various mission phases.

3.2 Manufacturing.- MSC will be responsible for providing the Lunar Excursion Module GFE and its associated GSE. The Principal Contractor will provide the Command Module, Service Module, and all adapters.

3.3 Operations.- The NASA will direct the Spacecraft prelaunch, launch, flight, and recovery operations. The NASA will provide all Spacecraft launch site facilities, overall prelaunch and launch countdown procedures, flight crews, and medical support. The Principal Contractor will support the operations relative to the Spacecraft. He will check-out and prepare the Command and Service Modules and associated ground support equipment and integrate the overall Spacecraft prelaunch operations.

3.4 Reliability.- As an integral part of the design and development of the Spacecraft, the Principal Contractor will implement a reliability program to assure compliance with mission reliability and safety requirements. The Principal Contractor will apportion a reliability goal to the Contractor and assess and monitor the Contractor's reliability program and performance.

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4.0 PROGRAM MANAGEMENT

4.1 NASA Organization

4.1.1 Over-All Direction. - The Director, Office of Manned Space Flight Programs, is responsible for over-all direction of Project Apollo.

4.1.1.1 Spacecraft. - The NASA Manned Spacecraft Center has been assigned system management responsibilities for the Apollo Spacecraft including Test Launch Vehicle Development and operations control and computing centers.

4.1.2 MSC Apollo Spacecraft Project Office. - The Apollo Spacecraft Project Office of the NASA Manned Spacecraft Center is responsible for planning, supervising, and directing all activities associated with the accomplishment of the Apollo Spacecraft project. In this capacity, the Project Office is responsible for and has authority for supervision and direction of the Lunar Excursion Module development. Primary functions which will be performed by the Apollo Spacecraft Project Office include:

a. Supervision and direction of the work of the MCS Apollo Contractors.

b. Determination and implementation of technical modifications, changes, or revisions in the work undertaken by the MSC Contractors.

c. Supervision and monitoring of working relationships and resolving technical problems which may arise between various MSC Contractors, which are not directly resolved between the parties concerned.

d. Maintaining close liaison with all Apollo Contractors in order to keep fully and currently informed on the status of contract work, potential schedule delays, or problems which may delay project progress.

Responsibilities and procedures in these areas are discussed in greater detail in subsequent sections of this document. In carrying out these functions the Apollo Spacecraft Project Office will locate personnel at the site of contract work as required.

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No technical direction which results in a change to this Statement of Work will become effective until receipt by the Contractor of a Contract Change Order or Contract Modification issued by the Contracting Officer pursuant to the clause of the contract entitled "Changes".

4.1.3 Monitoring. - The Apollo Spacecraft Project Office will monitor all technical activities of the Contractor to provide technical direction, implementation, and coordination; to resolve and expedite problem areas; to assist in achieving reliability goals and quality assurance; and to provide technical surveillance of design, testing, and manufacturing operations.

Authorized representatives of the MSC shall have the right to visit Subcontractors' plants at all times during the performance of this contract for making any inspections or obtaining any required information. Such visits will be coordinated with the Contractor.

4.1.4 Coordination. - The MSC Apollo Spacecraft Project Office will arrange and coordinate all contacts and meetings and will provide for technical coordination between the NASA contractors, the Manned Spacecraft Center, other NASA organizations, and other government agencies as required to assist all levels in obtaining information, data, and assistance necessary for accomplishment of the project.

4.1.5 Data Submittal. - The Contractor shall submit all technical information, documentation, and data to the MSC Apollo Spacecraft Project Office. Other simultaneous parallel paths of distribution may be specified as the need arises. All additional distributions shall be subject to prior MSC Apollo Spacecraft Project Office approval.

4.2 Contractor Organization.

4.2.1 Project Organization. - The Lunar Excursion Module Contractor shall establish a strong Apollo organization headed by a Program Manager and removed from other Contractor programs to the extent necessary to prevent interference with a timely completion of the Apollo program. He shall have the responsibility and necessary authority for the accomplishment of the Lunar Excursion Module development.

4.2.2 Organization. - Consistent with good practice and to the extent necessary to preclude interference from existing or future projects, the Contractor shall adequately organize all elements, functions, and services required to accomplish the Lunar Excursion Module development into an appropriate organization responsible to the Program Manager.

4.2.3 Staff Offices. - The Contractor shall maintain, within his Apollo organization, staff offices to assure the utilization of efficient engineering methods and management practices. These offices shall include the necessary functions to adequately control the program. The functions shall consist of but not be limited to:

Program control

System integration

Subcontractor control

Cost control

Reliability control

Documentation

NASA-MSC liaison

4.2.3.1 Engineering Changes. - A formal procedure shall be established for reviewing contract change proposals to assure that all technical, planning, and cost aspects of the proposed changes are considered.

4.2.3.2 Subcontract Administration. - A staff group of subcontract specialists covering all essential disciplines shall assume responsibility for coordination of subcontract work. The Contractor shall establish and maintain resident field offices at the plants of major Subcontractors as required.

4.2.3.3 Reliability Organization. - The reliability plan shall identify the organization responsible to management for the over-all reliability function and shall clearly define its responsibility for both policy and action. It shall stipulate the authority delegated to this organization to enforce its policies and assure necessary action. Line organization responsibilities and the relationship between line, service, staff, and policy organizations for reliability shall be identified. The reliability organization shall report to top management and receive top management support.

4.2.4 Delineation of Organization. - A delineation of the Contractor's management organization and procedures shall be included as part of the program plan specified in Paragraph 4.3.2.1 and shall include the following:

a. The responsibilities of the various portions of the Contractor's organization.

b. The division of responsibilities between the Contractor and Subcontractors.

c. The specific program control techniques to be used.

d. The provisions for an orderly flow of communications within the Contractor's organization and with Subcontractors.

4.2.5 Principal-Associate Contractor Relations. - The NASA Manned Spacecraft Center will approve the division of responsibilities between the various Apollo Spacecraft Contractors. The Contractor, supported by each other Associate Contractor, shall determine, mutually agree upon, and document operation procedures and interface definitions, specifications and control methods. Each document shall require MSC approval.

4.2.5.1 Principal Contractor. - North American Aviation, Inc., Space and Information Systems Division is the Apollo Principal Contractor.

4.2.5.2 Navigation and Guidance System Associate Contractor. - The Massachusetts Institute of Technology, Instrumentation Laboratory is the Apollo Associate Contractor for the Navigation and Guidance System.

4.3 Program Control.

4.3.1 General. - The MSC will exercise program control through use of program planning documents, periodic reviews, PERT. cost reports and such other management tools as may be required, including frequent scheduled and nonscheduled meetings.

4.3.1.1 Periodic Reviews. - Periodic technical and management program progress reviews of all aspects of the Contractor's work will be conducted by the MSC. These reviews will be conducted at the Manned Spacecraft Center and at the Contractor and Subcontractor plants as required. These reviews are intended to encompass major developmental milestones and/or problem areas.

4.3.1.2 Mockup Inspections. - The MSC will conduct mockup inspections at the Contractor's plant. These inspections will cover the adequacy of the design of the Lunar Excursion Module, its systems, and their compatibility with other elements of the Spacecraft. Mockup inspections will progress from preliminary to final.

4.3.2 Program Planning. - The detailed program plans, schedule, and requirements prepared by the Contractor shall encompass the activities of all Subcontractors supporting the Contractor and shall indicate their relationship to each other. A common, systematic breakdown of the various elements of the project shall be used in the preparation of these plans, schedules, and requirements. These plans, schedules and requirements shall be documented as described in the following paragraphs. All plans and revisions shall be prepared in close coordination with MSC and shall be subject to approval by the MSC.

4.3.2.1 Program Plan. - This document shall be the basic document which describes the over-all plan for the development of the Lunar Excursion Module. The plan shall delineate the method by which the Contractor intends to comply with the Statement of Work. The plan shall summarize management and control functions, design and development approaches, test program requirements and plans, manufacturing, quality control, logistic support requirements and such other planning documents as are specified in the Statement of Work. It shall include master phasing charts and milestone charts for the over-all program; general management, technical, manufacturing, facilities, and support schedules; man power requirements for performance of the project; and detailed phasing charts. Each detailed phasing chart shall portray important activities, their beginning and completion points and points at which decisions must be made. The approved program plan shall be used by the Contractor to guide his efforts. Anticipated schedule problems shall be identified and the intended method for their solution indicated.

4.3.2.2 Facilities Plan. - This plan shall cover the complete requirements for facilities for the Lunar Excursion Module and shall identify those which are to be government furnished. Industrial, development, range, operations, and all other facility requirements shall be described in detail, including any necessary modifications of existing facilities. Schedules showing required availability and modification dates, and plans for accomplishing necessary design and construction shall be included.

4.3.2.3 Test Plan. - The Contractor shall provide a test plan for the entire Lunar Excursion Module development program. The plan shall cover all types of tests required including such items as significant engineering development tests, design verification tests, tests to determine operating environments or conditions, qualification tests, and prelaunch tests. It shall outline the types and quantities of tests to be run, equipment and configurations to be tested, concepts and objectives of the tests, test locations, support requirements, major time phasing, and shall identify those which are to be performed by the government.

4.3.2.4 Manufacturing Plan. - The Contractor shall provide a manufacturing plan including such items as plans, schedules, methods, and controls.

4.3.2.5 Reliability Plan. - The Contractor shall prepare a reliability plan in accordance with Mil-R-27542 (USAF).

4.3.2.6 Maintenance Plan. - The Contractor shall prepare a maintenance plan which describes the detail requirements necessary to provide for the maintenance of all equipment throughout all phases of the program. The plan shall include maintenance during factory testing, storage, assembly, and prelaunch testing.

4.3.2.7 Support Plan. - The Contractor shall prepare a support plan which describes his support of the Lunar Excursion Module. The Contractor's support shall be consonant with the participation of the NASA and other contractors. The support plan shall include a description of all required functions of equipment overhaul, material (spares) support, transportation, and preparation of support manuals. Material support considerations shall include the methods of selection, distribution and control of spare parts, and the disposition of obsolete spare parts. Transportation considerations shall include the total transportation including Lunar Excursion Module transportation, peculiar spare parts and GSE requiring transportation, and other pertinent transportation data. Packaging requirements shall be specified in the plan. Support manual considerations shall include requirements, scope of coverage, format, change program, and other pertinent information.

4.3.2.8 End-Item Test Plan. - The Contractor shall provide an End-Item Test Plan in accordance with the provisions of Paragraph 7.4.2.1 of Reference 11.

4.3.3 PERT. -The NASA-PERT system will be utilized by the NASA as a management tool in scheduling, phasing, and controlling the Apollo Spacecraft program. Lunar Excursion Module PERT events, activities, and networks will be integrated with the total Apollo Spacecraft program PERT system. The NASA-PERT system will be implemented and maintained in accordance with the NASA-PERT Handbook.

4.3.3.1 Implementation. - The Contractor shall commence implementation of a PERT system for the Lunar Excursion Module within 30 days after letter contract award. Individual PERT networks shall be developed for each Lunar Excursion Module system and each major area of functional activity. The number of networks required and the scope of each network will be established by MSC after giving due consideration to the recommendations of the Contractor.

4.3.3.2 Reporting. - Reporting against networks shall commence after establishment and MSC approval of all Lunar Excursion Module PERT networks and shall be in accordance with NASA-PERT Handbook.

4.3.3.3 PERT Events and Activities Description Documents. - The Contractor shall prepare, submit, and maintain PERT Events and Activities Description Documents. The Contractor shall provide detailed descriptions of the events and activities which comprise the PERT networks required by the ASPO, MSC. The documents will be adjuncts to the PERT networks.

4.3.4 Program Milestone Reports. - The Contractor shall report program progress biweekly on NASA Form 491 in conformity with the instructions printed on the form. Milestone reporting by the Contractor will be utilized indefinitely, although the level of milestone detail will be reduced when the PERT reporting system is implemented.

4.3.4.1 Implementation. - The Contractor shall submit a list of proposed reporting milestones to MSC for approval 6 weeks after letter contract award. The Contractor shall commence biweekly milestone reporting within 12 weeks after letter contract award. Milestones for each Lunar Excursion Module system and major area of functional activity shall be submitted. System and activity milestones shall be grouped in a manner similar to the structure of the PERT networks. The milestones shall be selected in such a manner that 25 to 100 milestones for each system or activity will be scheduled for completion during the first year of the contract. Milestones for the remainder of the program may be limited to major items.

4.3.5 Financial Management. - Financial Management Reports will be prepared and submitted monthly by the Lunar Excursion Module Contractor. These summary and detail cost reports will provide direct engineering and labor manhours itemized by system, in addition to the normal cost for materials and vendor items, logistics and support, tooling and manufacturing and such other cost as is required for Financial Management and Auditing, in accordance with sound cost accounting practices. In addition to each system and subsystem being reported as a category of costing, the Lunar Excursion Module contract will report each subcontract, where the total cost of the subcontract exceeds $250,000, as a separate costing category. Direct manhours charged by the subcontractors as well as labor/engineering costs incurred will be reported for the subcontracts identical in form to the Lunar Excursion Module Contractor's inhouse effort.

4.3.5.1 Budget Forecast.- Unlike cost incurred, Budget Forecasts are not subject to audit by MSC, but rather are required as an additional management tool for analysis and for casting anticipated cost in the conduct of the total Project Apollo Program Financial Management operation. Quarterly budget forcasts will be required monthly. These forecasts will be prepared by the Lunar Excursion Module Contractor. Like the actual cost and direct manhours reported in the Financial Management Report, the budget forecast will be reported by systems and eventually subsystems. Each Subcontract will be budgeted as a separate planning category.

4.3.5.2 Implementation. - The first cost estimates and budget forecast will be prepared and submitted by the Lunar Excursion Module Contractor to the Apollo Spacecraft Project Office 6 weeks following letter contract award.

These estimates are to be designed for review for suitability by MSC, in conference with the Contractor, for format selection of cost categories and technique or method of the Contractor's ability to convert departmental accounting into realistic reporting categories.

A second report utilizing the methods, techniques, and format determined adequate and suitable by MSC will be submitted by the Lunar Excursion Module Contractor 12 weeks after letter contract award and upon approval of MSC, monthly thereafter throughout the life of the contract.

4.3.5.3 Categories. - The categories to be reported for the financial summary and detail cost reports and for the budget forecast shall be similar, if not identical, to the functional and system networks selected for PERT and Program Management Plan reporting. It is intended that separate cost accounting and budget forecast estimates will not exceed 25 separate categories, excluding the separate reports for each sub-contract.

4.3.5.4 PERT-Associates Cost. - As soon as is deemed practicable, cost reporting and budget forecasting will be PERT-network oriented. It is intended to designate PERT-Associated cost in such a manner as to reduce the level of effort by eliminating other costing techniques in use at time of implementation and at the same time improving the level of effort by providing more realistic cost reporting and budget forecasting by network event groupings or major milestones activities. The determination by MSC to convert to PERT-Associated cost will be made as soon as network approval,

4.3.5.5. Changes. - Any plans, schedules, or requirements proposed in accordance with Paragraphs 4.3.2, 4.3.3, and 4.3.4 and any revisions or changes thereto which affect the approved schedule of contract performance or appreciably increase or decrease the cost of the contract will require prior contractual coverage.

4.4 Deliveries.-

4.4.1 Schedule.- All hardware, data, operational support and such other material and services determined to be necessary shall be released to test activities or otherwise delivered in accordance with the Manned Spacecraft Center approved program.

4.4.2 Hardware List.- Commensurate with program requirements and lead times involved, the Contractor shall prepare and furnish a complete list of all deliverable hardware covered by this Statement of Work including a list of spares, a list of all hardware to be GFE, and a list of all GFP support items. A brief justification for each hardware item requirement and the delivery date(s) thereof shall be included.

4.4.3 Hardware Deliveries.- The deliverable hardware shall include the dummy, boilerplate, and prototype Lunar Excursion Modules, support equipment, mockups, spares, and materials as may be required for the Apollo program.

4.4.4 Mockups.- The mockups to be provided by the Contractor shall include but not be limited to the following:

Complete Lunar Excursion Module

Cabin Interior Arrangement

Cabin Exterior Equipment

Docking System

Environmental Control System

Crew Support System

Antenna Radiation Pattern

Handling and Transportation

Module Interface

4.5 Documentation.-

4.5.1 General.- The Contractor shall provide the documentation described in the following paragraphs in accordance with the delivery schedules, type classifications, and quantities listed in Table II. All documentation required shall be classified as one of three types. Type I documentation shall be submitted to the MSC for approval. Type II documentation shall not require approval but shall be submitted for coordination, surveillance, and/or information. Type III documentation shall be retained by the Contractor and made available to authorized representatives of the NASA for review, upon request. THE PREPARATION OF TYPE I DOCUMENTATION BY THE CONTRACTOR SHALL BE CONDUCTED IN CLOSE COORDINATION WITH THE NASA. IMPLEMENTATION OF TYPE I DOCUMENTATION SHALL NOT PROCEED UNTIL AFTER APPROVAL BY NASA OR UNTIL 20 DAYS AFTER SUBMITTED, WHICHEVER IS EARLIER.

4.5.1.1 Submission.- The Contractor shall submit all data and documentation to the MSC Apollo Spacecraft Project Office. Other simultaneous parallel paths of distribution shall be as specified by the MSC Apollo Spacecraft Project Office. All distributions shall be subject to prior MSC Apollo Spacecraft Project Office approval.

4.5.1.2 Document Revision.- The Contractor shall prepare and submit a method of document revision which will provide the MSC Apollo Spacecraft Project Office and other designated document recipients with the most current documentation as practicable.

4.5.2 Specifications.-

4.5.2.1 General.- The Contractor shall prepare the specifications indicated in the following paragraphs.

4.5.2.1.1 Ground Support Equipment Performance and Interface Specifications.- These specifications shall specify the function, performance, and interface requirements of the Lunar Excursion Module GSE and include qualification, reliability, and acceptance requirements.

4.5.2.1.2 Lunar Excursion Module Subsystem Specifications.- The Contractor shall prepare subsystem and other equipment specifications which define the function, performance, and configuration, and include qualification, reliability and acceptance requirements for the equipment which he furnishes.

4.5.2.1.3 Material, Parts, and Process Specifications.- The Contractor shall provide all material, parts, and process specifications which are used during the project. In cases where adequate materials and parts specifications do not exist, or are not suitable for the intended use, procurement specifications will be prepared by the Contractor. Where standards and process specifications covering items such as cleaning, forming, heat treatment, etc., are not available or are not adequate, process specifications will be prepared by the Contractor. Materials specifications shall include requirements relative to toxicity and fire hazards under environmental extremes.

4.5.2.1.4 Mockup Specifications.- The Contractor shall prepare a mockup specification for each mockup specified in this Statement of Work or as may be required. These specifications shall be submitted to NASA for approval prior to the start of mockup fabrication.

4.5.2.1.5 Training Equipment Specifications.- Training equipment specifications shall be prepared by the Contractor in coordination with NASA. A separate specification shall be prepared for each new piece of equipment and each equipment modification.

4.5.2.1.6 Final Specifications.- The Contractor shall furnish one complete set of reproducible procurement specifications for each Contractor-furnished system under this contract. Specifications shall be suitable for use in the procurement of any future systems.

4.5.3 Program Plans and Reports.-

4.5.3.1 Planning Reports.- The Contractor shall prepare and submit the program planning reports specified in Paragraph 4.3.2. The Contractor shall be responsible for maintenance of these plans through a revision system he will develop. All revisions shall be made with MSC Apollo Spacecraft Project Office approval. The program planning reports shall consist of the following documents:

Program Plan

Facilities Plan

Test Plan

Manufacturing Plan

Reliability Plan

Maintenance Plan

Support Plan

Training Plan

End-Item Test Plan

4.5.3.2 PERT Reports.- PERT reports shall be submitted in accordance with the NASA-PERT Handbook and NASA Management Instruction 4-1-5.

The Contractor shall submit a PERT Event and Activities Document as specified in Paragraph 4.3.3.3.

4.5.3.3 Monthly Financial Management Report.- This report shall consist of a monthly cost report in accordance with Paragraph 4.3.4 and the format shown in Appendix E.

4.5.3.4 Hardware List.- The Contractor shall prepare and submit a list of all deliverable hardware items in accordance with Paragraph 4.4.2.

4.5.3.5 Mockup Inspection Plan.- The Contractor shall prepare and submit a mockup inspection plan.

4.5.4 Progress and Status Reports.-

4.5.4.1 Monthly Progress Reports.- The Contractor shall submit monthly progress reports of all work accomplished during each month of Contract performance. For those months where a quarterly progress report is required, the report of monthly progress shall be included in the quarterly report. The monthly progress report shall cover the status of the development of the Lunar Excursion Module including management and major technical aspects, facilities and other similar items. A quantitative description of over-all progress, an indication of current problems which may impede progress and the proposed corrective action, and a discussion of the work to be performed during the next monthly reporting period shall be included.

4.5.4.2 Quarterly Progress Reports.- This report shall cover progress and status of the development of the Lunar Excursion Module including management and major technical aspects, facilities, and other similar items but excluding costs, for the preceding quarter. Major problems encountered and the solutions undertaken, or planned, shall be included. Any situation requiring MSC action or assistance shall be highlighted. Progress and status in relation to the master phasing and milestone schedules and any actual or anticipated changes thereto shall be shown, either by charts or by data sufficient to show this information on the charts previously submitted. In addition to factual data, these reports shall include a separate analysis section which interprets the results obtained, recommends further action, and relates occurrences to the ultimate objectives of the contract work. Sufficient diagrams, sketches, curves, photographs and drawings shall be included to convey the intended meaning.

4.5.4.3 Final Report.- The Contractor shall submit a final report which documents and summarizes the results of the entire contract work, including recommendations and conclusions based on the experience and results obtained. The final report shall include tables, drafts, diagrams, curves, sketches, photographs and drawings in sufficient detail to comprehensively explain the results achieved under the contract.

4.5.4.4 Weekly Launch Site Activities Reports.- This report shall cover the status of the launch site activities relative to the preparation of the Lunar Excursion Module.

4.5.4.5 Monthly Weight and Balance Reports.- The Contractor shall prepare weight and balance reports which provide continuous weight and balance information for all Lunar Excursion Module Equipment.

4.5.4.6 Emergency Action Reports.- These reports shall be used by the Contractor for reporting any urgent matters which, unless solved immediately, could cause serious program delay. Such reports shall be forwarded by the most expeditious means available. Such urgent matters shall include:

Strikes

Shortages of material and equipment in critical areas

Transportation tie-ups

Safety of flight problems

Critical development problems

Factors outside the Contractor's responsibility.

4.5.4.7 Quarterly Reliability Status Report.- The Contractor shall prepare reliability status reports which provide a comprehensive view of the reliability program including the current demonstrated reliability level for each major element and component, as defined in the reliability program plan; a discussion of reliability problems; failure analyses; and results of corrective action taken and corrective actions proposed. The Contractor shall propose recommendations for redesign, tradeoffs, etc., as a result of the analysis.

4.5.4.8 Still Photographs.- The Contractor shall provide still photographs in accordance with the detailed instructions and requirements of Appendix B.

4.5.4.9 Motion Picture Photography.- The Contractor shall provide 16-mm motion picture coverage in accordance with the detailed instructions and requirements of Appendix B.

4.5.4.10 Lunar Excursion Module Flight Reports.- A report showing the results of each flight test shall be submitted. Each such report shall consist of a detailed evaluation of the particular flight test and shall include the following types of information.

4.5.4.10.1 A section on the performance of each Lunar Excursion Module subsystem together with an analysis of any Lunar Excursion Module malfunctions and the probable cause of the subject malfunction.

4.5.4.10.2 A section devoted to unexpected significant Lunar Excursion Module difficulties, or results which are encountered during launch preparation, their bearing on future tests, and any corrective measures on product improvement proposed.

4.5.4.11 Lunar Excursion Module Equipment Status Report.- This report shall present a list of all launch vehicle equipment indicating pertinent characteristics, qualification status, required qualification status, usage, reuse, ability, importance to mission, and flight performance on each part.

4.5.4.12 Program Management Plan Reports.- The Contractor shall prepare Program Management Plan Reports which present milestones and schedule dates for each subsystem and each major area of Contractor effort. The milestones shall be selected such that at least one shall be scheduled for completion each month. The number of milestones presented for each subsystem or major area shall be at least 25 per year, but not more than 100. Milestones for the first year shall be detailed but those for the balance of the project may be limited to major actions.

4.5.5 Non-Scheduled Reports and Data.-

4.5.5.1 Technical Data, Reports, and Analyses.- The Contractor shall prepare technical reports which describe the studies, analyses, and results of the contractual effort. The reports shall be prepared at times when complete blocks of work have been accomplished and, if appropriate, as logical subdivisions thereof. Major technical areas shall not be combined in a single document, but shall be published individually. The individual reports shall cover such technical specialties as stress analyses, reliability analyses, failure-mode analyses, etc.

4.5.5.2 Design Information.- The Contractor shall establish a method of submitting and shall submit periodically, preliminary design information before finalization of design to assist in expediting the interchange of design data and to keep MSC technical design groups continually and currently apprised of the Contractor's activities, philosophy, approaches, solutions and design evaluations of all phases and facets of design. This procedure will allow MSC technical personnel the prerogative to comment before all design features are finalized and will tend to expedite the final approval of Type I documentation.

4.5.5.3 Materials Reports.- These reports shall be submitted in accordance with the clause contained in the contract schedule entitled, "Materials Reports."

4.5.6 Qualification Reports and Data.-

4.5.6.1 Qualification Status List.- The Contractor shall prepare and maintain a status list showing the planned and completed qualification of each part, component, and subsystem for which he is responsible. The basis for qualification of those parts and components for which qualification tests are not required shall be shown. Where qualification is based on qualifications tests conducted by the Contractor, the date of such tests and reference to the detailed test reports shall be shown.

4.5.6.2 Qualification Test Reports and Data.- Data showing the results of all qualification tests shall be maintained and indexed in a master file by the Contractor. Reports shall be forwarded to the NASA Apollo Spacecraft Project Office showing the results of all qualification tests.

4.5.6.3 Failure Data.- The Contractor shall prepare failure reports on all failures which occur on Contractor-furnished and Government Furnished Equipment during all phases of testing, operation, etc.

4.5.6.4 Monthly Failure Summary.- The Contractor shall prepare a monthly failure summary which summarizes the failure reports prepared above.

4.5.7 Quality Control Reports.-

4.5.7.1 Acceptance Test Data Sheets.- Copies of data sheets showing the results of acceptance tests performed by the Contractor on major end items of Ground Support Equipment and on major components of the Lunar Excursion Module shall be prepared and furnished for review by the NASA Manned Spacecraft Center. Acceptance test data on all other items shall be maintained by the Contractor and shall be made available for review by representatives of the NASA Manned Spacecraft Center upon request.

4.5.7.2 Data and Reports on Other Tests.- Data showing the results of all required tests not otherwise provided for herein, which are the responsibility of the Contractor, shall be recorded and maintained on file. Reports shall be submitted on each of these tests or test series.

4.5.7.3 Special Sampling Plans.- The Contractor shall provide special sampling plans (defined as those other than military standard sampling plans) in accordance with the provisions of Paragraph 12.3 of Reference 11.

4.5.7.4 Quality Control Plan.- The Contractor shall provide a Quality Control Plan in accordance with the provisions of Paragraph 3.1 of Reference 11.

4.5.7.5 Inspection, Measuring, and Test Equipment Procedures.- The Contractor shall provide inspection, measuring, and test equipment procedures in accordance with the provisions of Paragraph 9.6 of Reference 11.

4.5.7.6 Monthly Quality Report.- The Contractor shall provide a Monthly Quality Report in accordance with the provisions of Paragraph 14.2 and Paragraph 14.3 of Reference 11.

4.5.7.7 Quarterly Summaries of Quality Control Performance Audits.- The Contractor shall provide quarterly summaries of quality performance audits in accordance with the provisions of Paragraph 15.2 of Reference 11.

4.5.7.8 Inspection and Test Procedures.- The Contractor shall provide inspection and test procedures in accordance with the provisions of Paragraph 7.3.1 of Reference 11.

4.5.7.9 Process Control Procedures.- The Contractor shall provide process control procedures in accordance with provisions of Paragraph 7.5.4.1 of Reference 11.

4.5.7.10 Storage Procedures for End Items.- The Contractor shall provide storage procedures for end items in accordance with the provision of Paragraph 11.5 of Reference 11.

4.5.7.11 Application of Sampling Plans.- The Contractor shall provide details of the application of sampling plans in accordance with the provisions of paragraph 12.3 of Reference 11.

4.5.8 Drawings.- Drawings, layouts of various major assemblies, inboard profiles, etc., required by the NASA for coordination, technical monitoring, and/or information shall be furnished to authorized representatives of the NASA upon request both prior to and subsequent to release.

4.5.8.1 Maintenance of Drawings.- The Contractor shall maintain a complete up-to-date set of Contractor and Subcontractor drawings sufficient to describe each of the equipments for which he is responsible. These drawings shall be prepared using the Contractor's internal drawing system and shall conform to high quality commercial standards.

4.5.8.2 Final Drawing Submission.- The Contractor shall submit on microfilm a set of engineering drawings sufficient to enable manufacture of any equipment or items furnished under the contract (other than components or items of standard commercial design or items fabricated heretofore); or a set of flow sheets and engineering drawings sufficient to enable performance of any process developed under the contract.

4.5.8.3 Drawing Approval.- Approval of Contractor's drawings will be general and will not relieve the Contractor from the responsibility for the correctness of the drawings furnished by him, nor for their compliance with the specifications, nor for proper fitting and construction of the work, nor for furnishing materials and work required by the contract which may not be indicated on the drawings when approved. The approval of the Contractor's drawings shall not be construed as approving changes in scope of the contract.

4.5.8.4 Drawing List.- The Contractor shall prepare a drawing list which presents all assigned drawing numbers, titles, release dates, effectivities, next assembly numbers, and next assembly titles. It shall include a brief description of each drawing. Periodic revisions shall reflect additions and deletions.

4.5.9 Support Manuals.- The Contractor shall prepare and provide manuals to define, in detail, operating instructions as well as maintenance, check-out, and test procedures as indicated in the following paragraphs. The instructions and procedures contained in the manuals shall be arranged to permit operation, maintenance, check-out or test of the equipment covered by the appropriate manual in the minimum feasible amount of time. The material shall be designed to be readily understood by the personnel who will operate and/or maintain the equipment.

4.5.9.1 Check-out Manuals.- The check-out manuals shall provide the procedure and information required to perform check-out tests of the appropriate systems. They shall permit complete check-out in the maintenance area or launch site.

4.5.9.2 Lunar Excursion Module Operations Manuals.- Lunar Excursion Module operation manuals shall define the detailed procedures required to perform the tasks directly associated with the Lunar Excursion Module prior to, including, and subsequent to launch. The manuals shall present, in sequential order, the instructions for tasks performed by members of the team who participate in Lunar Excursion Module operations.

4.5.9.3 Lunar Excursion Module Flight Operation Manual.- This operation manual shall provide the instructions and procedures to be followed by the crew involving the Lunar Excursion Module. The tasks to be performed by the crew shall be presented in a logical sequence in individual sections pertinent to each phase of the mission.

4.5.9.4 Maintenance and Repair Manuals.- These manuals shall provide complete instructions and procedures for the maintenance and repair of the Lunar Excursion Module and associated Ground Support Equipment. A manual shall be provided for each major item of equipment or subsystem.

4.5.9.5 Lunar Excursion Module Familiarization Manual.- The familiarization manual shall provide a description of the complete Lunar Excursion Module. Each operational system shall be described in general terms but with sufficient detail to convey a clear understanding of the system as a whole. This manual shall cover the general operational procedures and include a reference index of all support manuals. This manual shall serve as an orientation-indoctrination type document and as a reference document containing information relative to all systems and major components.

4.5.9.6 Ground Support Equipment Manuals.- A manual shall be provided for each major item of Ground Support Equipment. The manuals shall contain all the procedural instructions directly associated with, and required for, operation and check-out of the ground support equipment.

4.5.9.7 Description Manuals.- A Description Manual shall be prepared for each Lunar Excursion Module intended for flight and shall provide a description of the complete module and associated GSE. Each operational system shall be described in sufficient detail to indicate its operating characteristics and limitations. Deviations of detail design or operation from that which is established as standard for "protection" items should be specifically identified. The manuals will serve as a series of documents that establish the exact configuration of each module and its associated GSE. Timely revision and updating of each manual shall be provided for.

4.5.9.8 Transportation and Handling Manuals. - These manuals shall provide the procedures and special requirements for transportation, handling, and storage of the Lunar Excursion Module and major items of GSE.

4.5.9.9 Training Manuals. - The Contractor shall provide training manuals for the NASA-conducted flight crew and ground crew training programs associated with the training equipment supplied by the Contractor. Each trainer or part trainer supplied by the Contractor shall be provided with a maintenance manual giving complete instruction for repair and maintenance of the equipment and an instructor's manual which shall include operating instructions and a recommended syllabus for the use of the trainer. A flight operational training manual (s) shall be provided suitable for use in the combined flight crew and flight monitor training. This manual shall describe operational characteristics of the equipment in terms of the displays available to the flight crew and ground crew. It shall describe the major types of malfunctions and how they may be isolated by ground and flight crews. A recommended syllabus for flight monitor-flight crew combined exercises shall be provided.

APPENDIX A

TECHNICAL APPROACH

3.0 INTRODUCTION. - The Technical Approach Section presents a technical description of the operational and flight plans and systems approach for the Apollo Spacecraft. The description constitutes a technical framework within which the initial design and operational modes of the Spacecraft are to be further developed. Section 3.4.3 describes the characteristics of the major systems of the Lunar Excursion Module. Other sections contain information which is also pertinent to the development of the Lunar Excursion Module.

The Apollo Spacecraft, operational, and flight plans described herein are defined by the requirements of the ultimate mission, lunar landing, and return. The resulting basic systems are then considered to be off-loaded for intermediate missions and qualification flights.

Several techniques for effecting earth and/or lunar-launch have been investigated with consideration given to capabilities of various launch vehicles and operational know-how. The Spacecraft System described is designed for direct earth-launch and a lunar orbit rendezvous technique for performing the lunar-landing and lunar launch phase.

3.1 <u>MISSION DESCRIPTION</u> - The lunar orbit rendezvous technique involves the injection of the complete Apollo Spacecraft into a translunar trajectory using one Saturn C-5 Launch Vehicle. The Spacecraft is composed of the Command, Service, and Lunar Excursion Modules. After injection and prior to the first midcourse correction, the Lunar Excursion Module is repositioned from its stowed position in the Spacecraft Adapter to a docked position with the Command Module Airlock System. The Service Module Propulsion System is used for performing the midcourse maneuvers and for placing the Spacecraft into a lunar orbit. In lunar orbit the Lunar Excursion Module with two crew members aboard separates from the Command Module and descends to a lunar landing. The third crew member remains in the Command Module in lunar orbit. The Lunar Excursion Module crew performs their lunar exploration and return to lunar orbit with their records and specimens. The Lunar Excursion Module crew performs a rendezvous and docking maneuver with the Command Module. The crew and payload transfer to the Command Module and the Command Module, with or without the Lunar Excursion Module, is injected into a transearth trajectory by the Service Module Propulsion System.

3.2 PROJECT IMPLEMENTATION CRITERIA - Considerations which determine the design of the Apollo Spacecraft, its operation, and ground support activity are presented in this section.

3.2.1 Technical Guidelines. - The Technical Guidelines are the collection of principles to which the basic technical approach of the space vehicle system must be responsive. They are the first-order criteria from which successive design criteria, performance margins, tolerances, and environments are developed.

3.2.1.1 Space Vehicle Concept. -

3.2.1.1.1 Launch Vehicle. - The Saturn C-5 Launch Vehicle shall be the basic launch vehicle for lunar missions. Earlier phases will employ other Saturn Launch Vehicles, and other launch vehicles may be used for certain development and/or qualification flights.

3.2.1.1.2 Spacecraft. - The Spacecraft shall be composed of separable modules such that (1) "effective weight" principles can be realized through proper jettisoning of expendable units (2) performance benefits can be obtained by utilizing staging techniques and (3) module configurations peculiar to specific missions can be modified without substantial effect upon modules common to general missions. The general features of the Spacecraft are described in the following paragraphs.

3.2.1.1.2.1 Command Module. - The Spacecraft shall include a recoverable Command Module which shall remain essentially unchanged for all Apollo missions.

3.2.1.1.2.1.1 Command Center. - The Command Module shall be the Space Vehicle command center where there are exercised all crew-initiated control functions during the launch, transearth, translunar and earth reentry phases. During the phase of the lunar landing mission in which the Command Module is separated from the Lunar Excursion Module each will have its crew initiated control functions unique to its module operation. As the command center, this module where practical shall contain the communication, navigation, guidance, control, computing, display equipment, etc., requiring crew mode selection. In addition, other equipment required during nominal and/or emergency landing phases shall be included in the Command Module. As the command center, this module shall include features which

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allow effective crew participation such as windows with a broad field of view for general observation, landing, rendezvous; equipment arrangements allowing access for maintenance; and simple, manually-operated functions in lieu of complex automation.

3.2.1.1.2.1.2 Housing. - The Command Module shall house the three crew members during launch, translunar, transearth and reentry phases. While the Lunar Excursion Module is separated from the Command Module for performing the lunar landing and return the Command Module will house one crew member. The Command Module shall provide for sufficient storage of experimental measurements obtained during flight to satisfy mission objectives.

3.2.1.1.2.1.3 Reentry and Earth Landing. - The Command Module shall be the reentry and earth landing vehicle for both nominal and emergency mission phases. The use of equipment such as ejection seats or personal parachutes is not precluded for certain cases.

3.2.1.1.2.1.4 Ingress and Egress. - Ingress and egress hatches to the Command Module shall not be obstructed at any stage of space vehicle countdown, flight, and recovery. Means of egress to free space without decompression of the entire Command Module shall be provided.

3.2.1.1.2.2 Service Module. - The Spacecraft shall include an unmanned Service Module which shall contain stores and systems which do not require crew maintenance or direct operation, and which are not required by the Command Module after separation from the Service Module. The Service Module shall house all propulsion systems except that required for lunar descent, landing, and launch and attitude control during earth-entry. The Service Module Propulsion System shall provide on a backup basis the propulsion required to successfully complete the lunar rendezvous manuever. Consideration shall be given to inflight maintenance of equipment in the Service Module by crewmen in extra-spacecraft suits. The Service Module may be modified in accordance with particular mission requirements, but the principal structural load paths, geometric arrangement, and configuration shall remain unchanged for various missions and project phases. It is expected that the Service Module would normally be jettisoned prior to reentry into the earth's atmosphere. The Service Module shall not be recoverable.

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3.2.1.1.2.3 Lunar Excursion Module. - The Spacecraft shall include a Lunar Excursion Module. This module will serve as a shuttle vehicle for transferring two of the crew members and payload from the Apollo Spacecraft to the lunar surface and back. The third crew member will remain in the Command Module of the lunar orbiting Spacecraft. The Lunar Excursion Module will allow for crew exploration in the vicinity of the lunar touchdown. The Lunar Excursion Module is not required to have lunar surface mobility. This module shall have the capability of performing the separation, lunar descent, landing, ascent and rendezvous independent of the Spacecraft. However, provisions will be made for the Command Module to communicate and perform various tasks to aid in the successful operation of the Lunar Excursion Module during this phase of the mission. The Command and Service Module shall provide on a backup basis the necessary guidance, control and propulsion to effect the rendezvous.

3.2.1.1.2.3.1 Crew Control. - The Lunar Excursion Module shall have a command center where there are exercised all crew-initiated control functions during the separation from the Command Module, lunar descent, landing and ascent and rendezvous and docking with the Command Module. This command center shall contain the communication, navigation, guidance, control, computing, display equipment, etc., requiring crew mode selection during lunar descent, landing, ascent and rendezvous. In addition, other equipment required during nominal and/or emergency phases shall be included in the Lunar Excursion Module. As the command center for the lunar landing operation, this module shall include features which allow effective crew participation such as windows with a broad field of view for general observation, landing, launching, rendezvous; equipment arrangements allowing access for maintenance; and simple, manually operated functions in lieu of complex automation. The Lunar Excursion Module shall not be recoverable.

3.2.1.1.2.3.2 Housing. - The Lunar Excursion Module shall house two crew members during lunar descent, landing, ascent and rendezvous. It shall also house equipment for measuring, storing, and/or transmitting those experimental measurements obtained during flight to satisfy mission objectives.

3.2.1.1.2.3.3 Ingress and Egress. - An ingress and egress hatch shall be provided in the Lunar Excursion Module such that the crew members can transfer between the Lunar Excursion Module and Command Module in a docked configuration without being exposed to the environment of space. An external hatch in the Lunar Excursion Module shall be provided to allow ingress and egress to the Lunar Excursion Module during countdown and allow exit into space while in the docked position.

3.2.1.1.2.3.4 Propulsion. - The Lunar Excursion Module shall house all propulsion systems required for separation from the Command Module, lunar descent, landing, ascent, rendezvous and docking.

3.2.1.1.2.3.5 Equipment. - The Lunar Excursion Module shall have an equipment area for housing stores and systems which do not require crew maintenance or direct operation. Consideration shall be given to part of the equipment being jettisoned while on the lunar surface. Consideration shall be given to inflight and lunar maintenance of equipment in the equipment area by crewmen in extra-spacecraft suits.

3.2.1.1.2.4 Spacecraft Adapter. - The Spacecraft Adapter shall structurally and functionally adapt the Service Module to the launch vehicle for non-lunar landing and lunar landing configurations. The Lunar Excursion Module shall be capable of being stowed in the adapter.

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3.2.1.2 <u>Operational Concept</u>. -

3.2.1.2.1 <u>Mission Profiles</u>. - The Spacecraft shall be designed with the capability of performing a variety of missions including earth orbital, circumlunar, lunar orbit, and lunar landing.

3.2.1.2.2 <u>Manning of Flights</u>. - The Spacecraft shall be designed for manned operation with no system requirement for unmanned missions. Where unmanned development flights are required specially equipped Spacecraft will be used

3.2.1.2.3 <u>Onboard Command</u>. - The primary command and decision-making responsibility shall be onboard the Spacecraft. The Spacecraft shall have the capability to perform the mission independent of ground-based information. This shall not preclude the use of ground-based information for crew use to increase reliability, accuracy, and performance. The Lunar Excursion Module shall have the capability to perform its phase of the mission independent of the Command Module and ground-based information.

3.2.1.2.4 <u>Flight Crew</u>. - The Spacecraft flight crew shall consist of three men. The flight crew for the Lunar Excursion Module operation during lunar descent, landing, ascent and rendezvous shall consist of two of the three Spacecraft crew members. The third crew member remains in the Command Module in lunar orbit.

3.2.1.2.4.1 <u>Crew Participation</u>. - The flight crew shall control or direct the control of the Spacecraft throughout all flight modes. They shall participate in navigation, control, monitoring, computing, repair, maintenance, and scientific observation when advantegous. Status of systems shall be displayed for crew assessment and operational mode selection including Spacecraft and launch-vehicle-systems status, staging sequences, and touchdown control. The Spacecraft shall be designed so that any single crewman will be able to perform all tasks essential to return the Command Module. The Lunar Excursion Module shall be designed so that any single crewman will be able to perform all tasks essential to return the Lunar Excursion Module to the Command Module and successfully performing the rendezvous and docking maneuver.

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3.2.1.2.4.2 Crew Mobility. - The onboard command guideline requires a considerable degree of crew mobility. Towards this end, a "shirtsleeve" environment shall be provided in the Command Module during all flight phases. The crew of the Lunar Excursion Module during its normal operation will be in extra-spacecraft suits with open face plates.

3.2.1.2.4.3 Automatic Systems. - Automatic systems shall be employed to obtain precision, speed of response, or to relieve the crew of tedious tasks; but crew monitoring of these systems with provisions for crew override or mode selection is required.

3.2.1.2.4.4 Abort Initiation. - Initiation of abort and subsequent control of abort modes shall be primarily the responsibility of the crew. There shall be no abort responsibility assigned to ground command or automatic systems except during prelaunch and launch periods if there is insufficient time for crew action. In such event, abort may be initiated without crew cognizance but subsequent flight control shall be the responsibility of the crew. Automatic and manual abort sequence modes shall be available for crew selection.

3.2.1.2.5 Flight-Time Capability.

3.2.1.2.5.1 Flight Period. - The Command and Service Module systems shall be capable of performing at their nominal design performance level for a mission of 14 days without resupply. For lunar landing missions, 7 of the 14 days may be in lunar orbit. The Lunar Excursion Module systems shall be capable of performing at their nominal design performance level for a mission of 48 hours without resupply. A considerable amount of this time will be spent on the lunar surface and must be considered in the systems designs.

3.2.1.2.5.2 Postflight Period. - The Command Module shall provide the crew a habitable environment for one day and a survivable environment for one week following a land or water landing.

3.2.1.2.6 Earth Landing. - The Spacecraft shall have the capability of initiating a return and earth landing maneuver at any time during either lunar or orbital missions. Prior to each flight, a primary ground landing site and suitable backup landing site will be selected for normal mission landing. Additional criteria apply as follows:

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3.2.1.2.6.1 Lunar Missions.- Alternate landing sites shall be designated prior to flight such that a landing is possible at these sites regardless of the time of reentry.

3.2.1.2.6.2 Earth-Orbital Mission.- The Spacecraft shall be capable of landing at the primary landing site (or at the backup site) from at least three orbits per day. In addition, alternate sites which may involve either land or water landing will be designated such that at least one alternate site can be reached for a landing from each orbit.

3.2.1.2.7 Lunar Landing.- The Lunar Excursion Module will be restricted to landing sites within $\pm$ 10 degrees of latitude to the lunar equator.

3.2.1.2.8 Ground Monitoring and Communication.-

3.2.1.2.8.1 Earth-Orbital Missions.-

3.2.1.2.8.1.1 Monitoring.-

3.2.1.2.8.1.1.1 Powered Flight.- There shall be continuous monitoring of onboard system and crew status during powered flight.

3.2.1.2.8.1.1.2 Orbital Flight.- Flight progress, onboard systems operation, and crew status shall be monitored by the ground operational Support System, a minimum of one contact with the Spacecraft per hour.

3.2.1.2.8.1.2 Ground Communications.- The network shall operate on a centralized control basis.

3.2.1.2.8.1.3 Lunar Missions.- The Spacecraft shall be designed to permit the Lunar Excursion Module, Command Module, and earth stations to communicate directly with one another, except when shielded by the moon in which case advantage may be taken of any station's relay capability. When the Spacecraft is on the far side of the moon, consideration should be given to the possibility of storing on tape telemetry data and voice to be played back upon emerging from moon shielding.

3.2.1.2.9 Apollo Control Center.- All phases of Apollo missions shall be directed from an Apollo Control Center.

3.2.1.2.10 Communications Center.- All mission communications during Apollo missions shall be controlled by the Apollo Control Center.

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3.2.1.2.11 Tracking and Ground Instrumentation Network.- All existing networks and associated facilities shall be considered for support of an Apollo mission where practical.

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3.2.1.3 <u>Reliability and Crew Safety</u>. - Mission reliability and crew safety goals, assuring a launch vehicle reliability of 0.95 and including the effect of ground complex reliability, but excluding consideration of radiation and meteoroid impact, shall be as follows:

3.2.1.3.1 <u>Mission Reliability</u>. - The probability of accomplishin the mission objectives shall be 0.90. The Lunar Excursion Module shall have a reliability apportionment of 0.984.

3.2.1.3.2 <u>Crew Safety</u>. -

3.2.1.3.2.1 <u>Nominal</u>. - The probability that none of the crew men shall have been subjected to conditions greater than the nominal limits specified in Design Criteria, shall be 0.90.

3.2.1.3.2.2 <u>Emergency</u>. - The probability that none of the crewmen shall have been subjected to conditions greater than the emergency limits specified in Design Criteria shall be 0.999. The Lunar Excursion Module shall have an apportionment of 0.9995.

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3.2.2 Design Criteria. - Design and operational procedures shall be conducted in accordance with rational design principles.

3.2.2.1 Limit Conditions. - The design limit load envelopes shall be established by superposition of rationally deduced critical loads for all flight modes. Load envelopes shall recognize the cumulative effects of additive-type loads. No system shall be designed incapable of functioning at limit load conditions.

3.2.2.2 Spacecraft Maintenance. - Equipment arrangements, accessibility, and interchangeability features that allow efficient preflight and inflight servicing and maintenance shall be given full consideration. The use of automatic checkout equipment shall not preclude manual entrance into and checkout of the system being checked. Design considerations shall also include efficient mission scrub and recycle procedures.

3.2.2.3 Ground Handling. - Full design recognition shall be given to the durability requirements of Spacecraft equipment and systems subjected to the continuous handling and "wear-and-tear" of preflight preparation.

3.2.2.4 Command Module Reuse. - The Command Module and internal systems shall be designed for repeated mission reuse after recovery. The internal systems shall be designed for an operational life of three nominal missions, exceptions are made for systems and components normally classified as expendable and those flight items which would be unduly compromised in design by environmental conditions occurring after their operational function has been performed.

3.2.2.5 Command Module Water Stability. - Command Module flotation and water stability characteristics shall be such as to ensure that the Command Module will recover from any initial attitude and will float upright with normal egress hatches clear of the water. Spacecraft seakeeping capability shall be such as to ensure a 7-day flotation period.

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3.2.3 Performance Criteria.- Rational margins shall be apportioned to systems and components such that the greatest overall design efficiency is achieved within the Launch Vehicle capabilities and implementation criteria constraints. The following specific systems margins are derived from rational consideration of past and anticipated operational experience. They are to be used as design criteria until experience justifies modification.

3.2.3.1 Multiple Failure.- The decision to design for single or multiple failures shall be based on the expected frequency of occurrence as it affects system reliability and safety.

3.2.3.2 Fail Safe.- System or component failure shall not propagate sequentially, i.e., design shall "fail safe".

3.2.3.3 Design Margins.- All Spacecraft systems shall be designed to positive margins of safety.

3.2.3.4 Repressurization.-

3.2.3.4.1 Command Module.- The repressurization system shall be designed for two complete cabin repressurizations, a minimum of 18 airlock operations, and a continuous leak rate as high as 0.2 lbs. per hour. Provisions shall be made for recharging portable life support systems ("back packs").

3.2.3.4.2 Lunar Excursion Module.- The repressurization system shall be designed for 6 complete cabin repressurizations, and a continuous leak rate as high as 0.2 lbs. per hour. Provisions shall be made for recharging portable life support systems ("back packs"). Normal "back pack" life is four hours and provisions should be made for five recharges.

3.2.3.5 Vacuum Operation of Cabin Equipment.-

3.2.3.5.1 Command Module.- Equipment which is normally operated in the pressurized cabin environment shall be designed to function for a minimum of four days in vacuum without failure.

3.2.3.5.2 Lunar Excursion Module.- Equipment which is normally operated in the pressurized cabin environment shall be designed to function for a minimum of two days in vacuum without failure. Time period in vacuum prior to operation shall be a minimum of 4 days.

[redacted]

3.2.3.6 Thermal Resistance.- The Spacecraft modules shall be designed such that additional or lesser requirements in thermal resistance may be accommodated or taken advantage of without major overall design changes.

3.2.3.7 Meteroid Protection.- The Spacecraft modules shall be designed such that additional or lesser requirements in meteroid protection may be accommodated or taken advantage of without major overall design changes.

3.2.3.8 Radiation Shielding.- The Spacecraft modules shall be designed such that additional or lesser requirements in radiation protection may be accommodated or taken advantage of without major overall design changes.

3.2.3.9 Isolation of Modifications.- The Spacecraft modules and systems shall be designed such that general modifications to one module or its systems do not propagate through the other modules.

3.2.3.10 Advances in Technology.- Flexibility shall be incorporated into the design such that advantage can be taken of advances in technology.

3.2.3.11 Off-the-Pad Capability.- The Launch Escape Propulsion System shall be capable of lifting the Command Module off the launch vehicle on the pad to an altitude of 5000 feet and a lateral range at touchdown of at least 3000 feet.

3.2.3.12 Special Flight Loads.-

3.2.3.12.1 Tumbling at Maximum Dynamic Pressure.- Primary Command Module structures are to be designed for loads arising from a "tumbling" of the escape vehicle at maximum dynamic pressure during launch.

3.2.3.12.2 20g Reentry.- Primary Command Module structures are to be designed for a limit load of 20g during reentry.

3.2.3.12.3 Noise.- The design shall accommodate sound pressure levels of 166 db in the frequency range 4 to 9600 cps emanating from the Launch Escape Propulsion System during both launch and abort modes.

3.2.3.12.4 Buffet.- The design shall accommodate a buffet pressure of 1.5 psi (rms) in the frequency range of 0 to 4 cps on the Service Module and Adapter during the earth-launch phases.

[redacted]

[redacted]

3.2.3.13 Structural Design Factors.-

3.2.3.13.1 Ultimate Factor.- The ultimate factor shall be 1.5 applied to limit loads. This factor may be reduced to 1.35 for special cases upon rational analysis and negotiation with Manned Spacecraft Center.

3.2.3.13.2 Pressure Vessel Design Factors.- Pressure vessels are to be designed using the following factors based on limit loads.

3.2.3.13.2.1 Pressure Vessel Proof Factor.- The proof factor shall be 1.33 when pressure is applied as a singular load. This factor may be reduced for special cases upon rational analysis and negotiation with Manned Spacecraft Center.

3.2.3.13.2.2 Pressure Vessel Ultimate Factors.- The ultimate factor shall be 2.00 when pressure is applied as a singular load. This factor may be reduced to 1.5 for special cases upon rational analysis and negotiation with Manned Spacecraft Center. The main propellant tanks are a special case and will have an ultimate factor of 1.5.

3.2.3.13.3 Pressure Vessel Limit Loads.- Limit loads shall be obtained with limit pressures. When pressure effects are relieving, pressure should not be used.

3.2.3.13.4 Pressure Stabilized Structures.- No primary structures shall require pressure stabilization.

[redacted]

3.2.4 Nomenclature. -

3.2.4.1 Reference Axes. - The reference axes of the Spacecraft shall be orthogonal and identified as shown in figure 1. The reference is to the crew members in their normal earth launch position in the Command Module. All of the modules shall use the same reference axes system.

3.2.4.1.1 X-Axis. - The X-Axis shall be paralled to the nominal launch axis of the Space Vehicle and be positive in the direction of initial flight.

3.2.4.1.2 Y-Axis. - The Y-Axis shall be normal to the X-Axis and positive to the right of a crewman when the crewman is facing towards positive X.

3.2.4.1.3 Z-Axis. - The Z-Axis shall be normal to both the X and Y axes and be positive in the direction of the crewman's feet.

3.2.5 Crew Requirements. - Design and operational procedures shall be in accordance with the crew requirements data presented here. The data presented are for various limits as defined below.

3.2.5.1 Nominal Limits. - Nominal limits are defined as the limits within which the crew's environment shall be maintained during normal operations.

3.2.5.1.1 Nonstressed Limits. - Nonstressed limits are defined as the environmental limits to which the crew may be subjected for extended periods of time such as orbit, lunar transit, and periods subsequent to normal landings.

3.2.5.1.2 Emergency Limits. - Emergency limits are defined as the environmental limits beyond which there is a high probability of permanent injury, death, or incapacity to such extent that the crew could not perform well enough to survive.

3.2.5.2 Metabolic Requirements. - The average daily metabolic requirements for each crew member are listed below.

Oxygen consumption	1.8 lb/day/man
Carbon dioxide output	2.3 lb/day/man
Heat output	11,300 BTU/day/man
Water consumption*	6.0 lb/day/man (This includes water in food; additional water may be required for sanitation.)
Food consumption	2800 Kcal/day/man

*Water consumption for the crew members while operating in the Lunar Excursion Module should be increased to 13.2 lb/day/man.

3.2.5.3 Crew Environment Requirements. -

3.2.5.3.1 Cabin and Suit Pressure. -

3.2.5.3.1.1 Command Module. - The cabin pressure nominal limits shall be 3.5 psia minimum and 15.0 psia maximum. The emergency limit shall be 3.5 psia minimum.

3.2.5.3.1.2 Lunar Excursion Module. - The cabin pressure nominal value shall be 5 psia. The suit is designed for a nominal 3.5 psia working pressure. The suit will be pressurized for inter-vehicular operation during normal cabin depressurization and for extra-vehicular operation.

3.2.5.3.2 Oxygen Partial Pressure. - The oxygen partial pressure nominal and emergency limits shall be 160 mm Hg minimum.

3.2.5.3.3 Carbon Dioxide Partial Pressure. - The carbon dioxide partial pressure nominal limit shall be 7.6 mm Hg maximum. The emergency limits are presented in figure 2.

3.2.5.3.4 Cabin Temperature. - The cabin temperature nonstressed limits shall be 70° F minimum and 80° F maximum. The stressed and emergency limits are presented in figures 3 and 4, respectively.

3.2.5.3.5 Cabin Relative Humidity. - The cabin relative humidity nonstressed limits shall be 40 percent minimum and 70 percent maximum. The stressed and emergency limits are presented in figures 3 and 4 respectively.

3.2.5.3.6 Radiation. - The nominal limit shall be the average yearly exposure tabulated in figure 5. The emergency dose limits shall be the maximum permissible, single acute emergency dose as tabulated in figure 5. Dosage calculations shall be based on the model presentation in figure 6. In the absence of sufficient information to assign dose value due to secondary radiation, a value of 50 percent of the primary dose will be used.

3.2.5.3.7 Noise. - The noise nonstressed limit shall be 80 db overall and 55 db in the 600 cps to 4800 cps range. The stressed limit shall be the maximum noise level which will permit communications with the ground and between crew members at all times. The emergency limit is presented in figure 7.

3.2.5.3.8 Vibration. - The vibration stressed, nonstressed, and emergency limits are presented in figure 8.

3.2.5.3.9 Sustained Acceleration. - The sustained acceleration limits for eyeballs out, down, and in conditions are presented in figures 9, 10, and 11. The limits presented were obtained from references 1 through 8, and are for currently available restraint systems, optimum body positioning, and without the use of G-suits. The sustained acceleration performance limits are defined as the maximum sustained acceleration to which the crew shall be subjected and still be required to make decisions, perform hand controller tasks requiring visual acuity, etc.

3.2.5.3.10 Impact Acceleration. - The impact acceleration nominal and emergency limits are presented in figures 12 and 13, respectively.

3.2.6 Natural Environment. - Design and operational procedures shall be in accordance with the natural-environment data presented here. It should be recognized that all natural-environment data required for the project are not included herein.

3.2.6.1 Launch. -

3.2.6.1.1 Atmospheric Pressure, Density, and Temperature. - The surface variation of atmospheric pressure, density, and temperature is given in reference 9.

3.2.6.1.2 Wind. - The direction, magnitude, and cumulative percentage of surface winds are given in reference 10.

3.2.6.1.3 Precipitation. - The average monthly precipitation is given in figure 14.

3.2.6.1.4 Thunderstorms. - The average number of hours per month during which there are thunderstorms is shown in figure 15.

3.2.6.1.5 Surface Temperature. - The maximum, minimum, and average temperatures are given in figure 16.

3.2.6.2 Flight. -

3.2.6.2.1 Atmospheric Phase. -

3.2.6.2.1.1 Atmospheric Pressure, Density, and Temperature. - The altitude variation of atmospheric pressure, density, and temperature is given in reference 9.

3.2.6.2.1.2 Wind. - The variation of wind with altitude is given in reference 10.

3.2.6.2.2 Mission Phase.

[redacted]

3.2.6.2.2.1 Solar Phenomena. - The hazards associated with an active sun are presented as a model solar event system with an indicated average frequency of occurrence.

3.2.6.2.2.1.1. Model Solar Event. - The time integrated model solar event is shown in figure 17. In arriving at this spectrum it is assumed that the flux of particles in energy range E to E + dE can be described by

$$\phi(E) = kt \qquad t < t_o$$
$$\phi(E) = k\left(\frac{t}{t_o}\right)^2 \qquad t > t_o$$

t_o (time of maximum flux) is related to energy by

$$E = e^{-.13t}$$

3.2.6.2.2.1.2 Probability of Encounter. - The probability of encounter of a solar event shall be assessed on the basis of total particles in the event. Figure 18 presents the average frequency for particles above 100 MEV over a seven-day mission. The total number of particles between 5 to 100 MEV range is shown in figure 17.

3.2.6.2.2.2 Van Allen Radiation Belts. -A description of the Van Allen radiation belts is presented in figure 19.

3.2.6.2.2.1 Inner Belt. - The inner belt is concentrated between the geomagnetic latitudes of 25 degrees North and 25 degrees South. It initiates as an altitude of 500 km and peaks in intensity at an altitude of 8500 km. The proton spectrum at the geomagnetic equator is presented in figure 20.

3.2.6.2.2.2.2 Outer Belt. - The outer belt is concentrated between the geomagnetic latitudes of 50 degrees North and 50 degrees South. It initiates at an altitude of 15,000 km, peaks in intensity at an altitude of 16,000 km, and decreases to a minimum intensity at an altitude of 21,000 km. The distribution of particles in the heart of the outer belt is presented in figure 21.

3.2.6.2.2.3 Meteroid Considerations. - The hazards involved in encountering meteroid will be assessed on sporadic activity only. The flux considerations for sporadic activity shall be based upon the Whipple distribution presented in figure 23.

[redacted]

3.2.6.2.2.4 Electromagnetic Radiation.- Electromagnetic radiation to be used for Spacecraft environmental analysis is presented in reference to its source.

3.2.6.2.2.4.1 Solar Radiation.- The electromagnetic radiation from the sun covering the spectrum from 60 angstroms to 1300 angstroms is given in figure 24, from 1300 angstroms to 2000 angstroms is given in figure 25 and from . 2 microns is given in figure 26.

3.2.6.2.2.4.2 Earth Radiation and Reflection.- The earth's albedo shall be considered as 35 percent. The remaining 65 percent shall be considered to be absorbed and some re-emitted as thermal radiation. The spectrum for the earth's albedo at local noon is given in figure 27. The radiation at the center of the dark side shall be considered to originate from a 251° K black body.

3.2.6.2.2.4.3 Lunar Surface Properties.- The physical characteristics of the lunar surface and topography are given in reference 16.

3.2.6.2.2.4.4 Background Radiation.- The background radiation from celestial sources shall be considered to be 10^{-4} ergs/cm^2sec in the interval 1230 to 1350 angstroms.

3.2.6.2.2.5 Interplanetary Atmosphere.- The interplanetary atmosphere shall be considered as shown in figure 30.

3.2.6.2.2.6 Space Background.- The space background electromagnetic radiation is presented above. The corpuscular radiation shall be considered as shown in figure 31 which represents the cosmic ray flux.

3.2.6.2.2.7 Earth Gravitational and Geometrical Constants.- The following earth gravitational and geometrical constants are to be used for tracking and orbital computations:

3.2.6.2.2.7.1 Symbols.-

a equatorial radius, meters

E oblateness factor = $\left(1 - \frac{\text{minor diameter}}{\text{major diameter}}\right)$

g acceleration of gravity at equator, meters/sec^2

G universal gravitational constant

h altitude above the reference ellipsoid, meters

J	harmonic terms of the potential function
M	mass
P_n	$(\sin\phi)$ Legendre polynomial
ϕ	latitude
r	radius from center of earth, meters
u,v,w	axis system ordinates, meters
U	potential function
ϕ	longitude
ω_e	rotational speed of earth $\dfrac{2\pi}{8.6.64.0982 + .00164T}$
T	Julian centuries (36525 days) from 1900 Jan 0.5 U.T.
A_u	astronomical constant

subscripts

e	earth
s	sun
p	planet
m	moon

3.2.6.2.2.7.2 <u>Gravitational</u>.-

3.2.6.2.2.7.2.1 <u>Numerical Values</u>.- In the formula

$$U = (GM_e/r)\ 1 - \sum_m J_m\ (a_e/r)^m\ P_n\ (\sin\phi)$$

Where P $(\sin\phi)$ is the Legendre polynomial and ϕ is the geocentric latitude, or in alternate notation:

$$(f,\phi) = \frac{GM}{r} e \left[1 + \frac{J}{3}\left(\frac{ae}{r}\right)^2 (1-3\sin^2\phi) + \frac{H}{5}\left(\frac{ae}{r}\right)^3 (3-5\sin^2\phi)\sin\phi + \frac{D}{35}\left(\frac{a_e}{r}\right)^4 (3-30\sin^2\phi + 35\sin^4\phi) \right]$$

$$GM_e = 3.986032\ (\pm 0.000030)\ X\ 10^{14}\ \frac{\text{meters}^3}{\text{sec}^2}$$

$J_2 = 1082.30\ (\pm 0.2) \times 10^{-6}$

$J_3 = -2.3\ (\pm\ 0.1) \times 10^{-6}$

$J_4 = -1.8\ (\pm\ 0.2) \times 10^{-6}$

$J_n = 0.0\ (\pm < 1.0) \times 10^{-6}\ n \geq 5$

$J_{nm} = 0.0\ (\pm < 2.0) \times 10^{-6},\ m \neq 0$

$a_e = 6.378165\ (\pm\ 0.000025) \times 10^6$ meters

$J = 1.62345 \times 10^{-3}$

$H = -0.575 \times 10^{-5}$

$D = .7875 \times 10^{-5}$

3.2.6.2.2.7.2.2 Remarks.

3.2.6.2.2.7.2.2.1 The values of $GM_e \cdot H$, D and a_e are consistent with the values of geodetic parameters.

$1/\varepsilon$ = Reciprocal of earth/flattening = 298.30

$g_e = 978.030\ \text{cm/sec}^2$

3.2.6.2.2.7.2.2.2 The values of a_e, e, g_e are those specified in the DOD World Geodetic System 1960 and are here recommended for the sake of consistency. In addition, they are close to the best estimates for these parameters. Reasonable alternative values based on terrestrial geodetic data; e.g., those in reference 11 differ by less than 20 meters is a_e, .00001 meters^2 in g_e, and 0.1 in 1/f.

3.2.6.2.2.7.2.2.3 The value of g_e incorporates a correction of .0013 meters/sec^2 to the Potsdam standard absolute gravity.

3.2.6.2.2.7.2.2.4 The values of J_3 and J_4 are compromises between the values obtained by the principal investigators of satellite orbits as presented in references 4, 5, and 6, with greatest weight to reference 6 and the given uncertainties are based on the discrepancies between these results. The values of J_2 by these same investigators range from 1082.19 to 1082.79×10^{-6}. The magnitude of effect of the omitted J_{nm} on satellite positions is about ± 400 m or less (see reference 12).

3.2.6.2.2.7.2.2.5 The most serious discrepancy of determination of gravitational parameters is between the GM from terrestrial data, 3.1986032 (± 0.000030) X 10^{14} meters^3/sec^2, and that based on the lunar mean motion and the radar measurement of the moon's distance: 3.986141 (± 0.000040) x 10^{14} meters^3/sec^2. This value depends on the moon/earth mass ratio of 1/81.375 (see reference 8); 3.986048 is obtained from Delano's 1/81.219 (see reference 13). However, the stated uncertainty depends mainly on the uncertainties in the radar measurement and the lunar radius.

3.2.6.2.2.7.3 Geometrical. -

3.2.6.2.2.7.3.1 Numerical Values. - Figure 32 represents the astro-geodetic geoid data station spacing and distribution. The Coordinate System used has its u, v, and w axes earth-centered, earth-fixed, and directed toward the latitudes and longitudes 0°, 0°; 0°, 90° E; and 90° N., respectively.

3.2.6.2.2.7.3.1.1 Corrections - General. - The corrections to be added to the rectangular coordinated in the u, v, and w system are presented in figure 33. These corrections are based on reference 11.

3.2.6.2.2.7.3.1.2 Corrections at Stations Not Connected to the Geodetic System. - Stations not connected to any of the principal Geodetic Systems, but which have an astronomic position or which are connected to a local system must be treated in the following way. The geodetic latitude and longitude is to be that of the astronomic or local system, and the u, v, and w coordinated obtained by the equations.

[redacted]

$$u = (\gamma + h) \quad \cos \phi \cos \lambda$$

$$v = (\gamma + h) \quad \cos \phi \sin \lambda$$

$$w = \left[(1 - e^2)\, \gamma + h\right] \quad \sin \phi$$

where

$$\gamma = a_e \, (1 - 3^2 \sin\phi)^{-\frac{1}{2}}$$

$$e = 2f - f^2$$

and h is the elevation above the ellipsoid. If $a_e = 6378165$ meters and $f = 1/298.30$ are used, and the height above the ellipsoid assumed to be identical with the height above sea level, then the standard error of position in the radial direction should be

$$\sigma(r) = \pm 45 \text{ meters.}$$

If the geoid heights from figures 2 or 3 of reference 3 are added to the height above sea level, then there will be a slight improvement to about $\pm$ 35 meters.

For the horizontal coordinates at a station in a geophysically stable continental area.

$$\sigma(r\,\phi) = \sigma\, r \lambda \cos \phi) \approx \pm 170 \text{ meters.}$$

For the horizontal coordinates from a single astronomic position on an island or in a geophysically disturbed area (mountains, etc.)

$$\sigma(\, r\,\phi) = \sigma\, r \lambda \cos \phi) \approx +350 \text{ meters.}$$

By using the mean position obtained by connecting astronomic observations on opposite sides of an island by traverse this may be improved to about

$$\sigma(r\,\phi) = \sigma\, r\, \lambda \cos \phi) \approx + 250 \text{ meters.}$$

By using topographic isostatic corrections of the deflections of the vertical this may further be improved to about

$\sigma(r\,\phi) = \sigma(r\,\lambda \cos \phi) \approx +200$ meters (for a single station) and $\sigma(r) = \sigma(r\,\lambda \cos \phi) \approx \pm 120$ meters (for the mean from observations on opposite sides.)

[redacted]

3.2.6.2.2.7.3.2 **Remarks.**

The values recommended for Argentina and Australia are based on the assumption of tangency at the geodetic datum "origins" of an a_e = 6378165+N_o, 1/298.3 ellipsoid, where N_o is the geoid height at the datum origin given in figures 2 and 3 of reference 11.

The Vanguard Datum was based on the assumption of tangency to NAD at its origin (97°N, 263°E) of the Hough Ellipsoid

a_e = 6378270

f = 1/297.0

The SAO SP 59 datum (see reference 14) is based on the assumption of tangency to the conventional datums, corrected by gravimetrically computed deflections, of the vertical (except in Argentina), of the International Ellipsoid

a_e = 6378388

f = 1/297.0

The large differences from reference 11 datum are due mainly to this use of an obsolete ellipsoid and secondarily to the utilization of much less observational data.

Note that all datum shifts are described as translations; there are no rotations. For properly observed geodetic systems, the orientation error is negligible. Orientation of geodetic systems is obtained from the stars through "Laplace stations," at which astronomic azimuth and longitude are observed.

The standard error for difference of position between two stations connected to the same geodetic control system should always be less than ± 20 meters.

The standard errors for astronomic positions in a continental area is based on autocovariance analysis of gravimetry.

The standard error for astronomic positions on islands is based on a sample of 69 islands in the West Indies connected to the continental geodetic system by Hiran trilateration.

3.2.6.2.2.8 Sun and Planetary Constants. - Certain sun, lunar, and planetary constants to be used are presented in figure 34.

3.2.6.2.3 Entry, Earth Landing, and Recovery Phase. -

3.2.6.2.3.1 Atmospheric Pressure, Density, and Temperature. - The altitude, seasonal, daily and latitude variation of pressure, density, and temperature will be as presented by the revised ICAO reference atmosphere. Because this reference is in the process of publication the 1959 ARDC standard atmosphere will be used until the ICAO data is available.

3.2.6.2.3.2 Wind Velocity. - The wind velocity which is exceeded only 10 percent of the time is presented in figure 35 for the months of July and January.

3.2.6.2.3.3 Wave Height. - The wave height which is exceeded only 10 percent of the time is presented in figure 36 for the months of January and July.

3.3 FLIGHT PLAN.

3.3.1 General. - Definitive flight plans for the various missions which will be included in the Apollo program can be formulated only after the design details of the Space Vehicle are better known, mission objectives defined in more detail, and more comprehensive information is available concerning the tradeoffs between the variables which describe each mission phase. There are, however, some requirements concerning flight plans and some information relative to the choice of trajectories which are presently known. The following sections present the preliminary requirements for flight plans, the effect of variations of certain mission parameters upon flight plans, and an example of a lunar landing mission trajectory.

3.3.2 Preliminary Flight Plan Requirements. - The following flight plan requirements are considered to be preliminary and a partial list. Further studies and experience in formulating flight plan and Spacecraft design details on the part of NASA, the Principal Contractor, and the Lunar Excursion Module Contractor will enable more definitive requirements to be specified.

a. Launch Site - All earth-orbit and lunar missions are to be launched from Cape Canaveral, Florida. This does not preclude the use of other launch sites for systems tests. The launch azimuths are to be within the limitations set by range safety and tracking considerations.

b. Launch Time Window - Lunar mission flight plans must include at least a 2-hour period on launch date in which the mission can be launched either continuously or at discrete intervals.

c. Number of Parking Orbits - Multiple parking orbits are acceptable.

d. Earth Orbits - Earth-orbit altitudes for manned orbital flight and parking orbits for lunar missions will be limited to altitudes from 50 to 400 nautical miles.

e. Translunar Insertion Position - Final insertion into the translunar trajectory shall be located such that the trajectory can be determined by the Ground Operational Support System within 15 minutes of translunar insertion burnout.

f. Translunar Midcourse Corrections - As a design objective the 3 σ velocity requirement for translunar midcourse navigation shall not exceed 500 ft/sec including the error in arrival velocity.

g. Lunar Landing - The lunar landing shall be initiated from a lunar orbit. The nominal orbit altitude is 100 nautical miles. A 10° plane change capability shall be supplied for establishing the initial orbit. The Lunar Excursion Module will separate from the Command and Service Module and transfer from the circular orbit to an equal period elliptical orbit which does not intersect the moon's surface.

h. Lunar Landing Site.- Mission plans may call for several lunar landing sites. The following factors will be considered in the choice of a landing site:

(1) Propulsion and fuel requirements.

(2) Maneuvering and hovering capability.

(3) Communication with GOSS.

(4) Illumination.

(5) Temperature of environment.

(6) Surface texture.

(7) Ease of identification.

i. Lunar Launch - There shall not normally be a requirement to reposition the spacecraft attitude prior to launch.

j. Transearth and Midcourse Corrections - As a design objective the 3 σ velocity requirement for transearth midcourse navigation shall not exceed 500 ft/sec. The inclination of the transearth trajectory to the earth's equator shall be compatible with existing tracking stations.

k. Reentry - The Command Module shall be capable of reentry over a nominal 30 nautical mile corridor with peak deceleration limited to 10g. The direction of reentry to be with the rotation of the earth.

3.3.3 Trajectory Characteristics.- The material is presented in the order of the different phases of flight.

a. Launch - Time Window - In order to provide a launch-time window it is necessary either to maneuver the Launch Vehicle or Spacecraft to intercept a planned nominal trajectory, or to select a new trajectory which will satisfy the mission objectives and which can be obtained at the actual launch time. Both the lunar trajectory selection and maneuvering of the Launch Vehicle methods of obtaining a launch window should be developed for use in the Apollo mission. The discussion of launch window below is limited to lunar trajectory variation.

To a first order of approximation, the Spacecraft can be injected into a lunar trajectory from any parking orbit which passes over the earth surface point which is formed by projecting the line of centers between the earth and the moon at the time of closest initial approach. With no restriction due to the mission objectives or performance loss, a launch could be made at any time of day. The launch window is, therefore, primarily a function of the permissible azimuth swing for launch from Cape Canaveral. Figure 37 shows the launch-time window and the maximum inclination of the parking orbit as a function of azimuth variations, positive and negative from due East launches from Cape Canaveral. This launch window is independent of lunar declination and can be obtained for lunar injection toward either the South or North.

b. Parking Orbits - Earth-orbit altitude from 50 to 400 N.M. may be required for earth-orbit launch time flexibility. It is expected that the best launch booster performance is obtained with low altitude parking orbits. A nominal value of orbit altitude for direct lunar missions is 600,000 feet. The effect of launch delays on the earth track of the parking orbit and the location of the injection point is shown in figure 38. The extreme orbit paths for a 4-hour launch window are shown as the outside solid lines for the condition where the launch azimuth variation is symmetrical, about a due East launch from Cape Canaveral. The inner broken lines show the extremes for a 2-hour launch window. The launch window results from the use of any trajectory between these extremes. The location of the injection points for some important lunar declination is shown in figure 38.

c. Injection - The characteristic velocity requirement for injection into translunar trajectories from a 600,000 foot parking orbit is shown in figure 39 for initial engine thrust to Spacecraft weight ratios from 0.5 to 1.5. Their results are applicable for a specific impulse from 250 to 500. Even though the results shown are terminated at 900,000 feet, it is apparent that with propulsion units with initial thrust to weight ratios less than 1.0, the injection is possible at 200 N.M. altitude without significant losses in performance.

The approximate area covered by the Mercury tracking network for 5^{o} elevation is shown in figure 40 for several altitudes. Comparing figures 38 and 40, it is apparent that many of the Mercury tracking stations are poorly located for coverage at injection of a 4-hour launch window. For maximum Northern declination of the moon, the injection point can be tracked for nearly 4 hours of launch window with the station in Australia. With the moon at maximum Southern declination, the injection point can be covered for about 3 hours of launch window with the tracking stations located in the USA. At lunar declination near 0^{o}, however, the launch-time window has restricted coverage. Relocation of some stations and addition of several more would be required to give adequate coverage at all declinations.

d. Translunar Trajectory Characteristics. - The nominal translunar trajectory for all lunar missions is one which has a coast return to the earth with acceptable reentry conditions. For circumlunar missions this trajectory must have a flight time and return inclination which returns the vehicle so that the primary landing area is within the reentry maneuver capability of the reentry vehicle. The translunar trajectories for lunar landing missions approach the moon to within 100 nautical miles altitude in order to minimize the landing propulsion requirements.

The inclination of the translunar trajectory plane is a function of the parking orbit inclination and the lunar declination as shown in figure 41. Varying the inclination of the parking orbit to obtain launch time tolerance as indicated in this section will result in a change in the translunar trajectory inclination which in turn will have some effect on the inclination of the lunar orbit unless plane changes are made during transfer.

The translunar trajectory is tracked with the deep-space network. Figure 42 shows the coverage of the existing deep-space network at various altitudes. About 15 minutes after injection, the translunar trajectory will be at high enough altitude for tracking.

e. Lunar Orbit - Flight plans require establishing a circular lunar orbit at 100 nautical miles altitude for lunar landing missions. For lunar orbit missions flight plans may call for both circular and elliptical orbits within the limits of propulsion requirements for the 100 nautical mile circular orbit. Velocity increments for establishing lunar orbits are shown in figure 43 (note, add 200 ft/sec for out-of-plane requirements).

f. Lunar Landings - A technique for lunar landing is illustrated in figure 44. The Spacecraft arrives behind the moon on a circumlunar trajectory, a transfer is made to a 100 N.M. circular orbit about the moon. The Spacecraft passes over the landing area once and then at the proper position in the orbit the Lunar Excursion Module will be separated from the Spacecraft and a transfer is made from the circular orbit to an equal period elliptical orbit having a pericynthion of 50,000 feet. The landing run is initiated at 50,000 feet altitude. The impulse requirements for landing on the moon for an optimum flight path for elliptical orbits having 100 nautical miles apocynthion and various pericynthions is shown in figure 45 for various initial thrust-to-weight ratios. Results are shown for termination of the landing run either horizontally or vertically at altitudes below 1000 feet.

g. Lunar Landing Site.- Figure 46 shows the lunar landing area available for missions with translunar trajectories which return to earth with posigrade reentry. The available landing area without orbit transfer is limited to a band of latitude approximately ± 10 degrees. The landing area is further restricted by the relation of the velocity at injection to the earth-moon plane. In general, the areas labeled N are available for injection with velocity directed toward the North and the areas labeled S with velocity vectors directed toward the South. Referring this information back to the parking orbit about the earth, it is observed that on the first pass injection toward the North will occur between longitude -100 to +90, which is generally over the Pacific Ocean. It is assumed that the first half of the parking orbit may be needed for systems check so that injection toward the South would be on the first half of the second orbit, roughly between -90 and +65 degrees longitude.

h. Lunar Launch.- The probable technique for launch of the Lunar Excursion Module from the moon on the return to the Command and Service Module is to lift off in an essentially vertical maneuver from the local surface and program pitch into an elliptical orbit. The orbit is circularized at apocynthion and rendezvous and docking with the Spacecraft initiated immediately. Injection on the transearth trajectory is made at the proper time. Figure 47 shows the characteristic velocity requirements for vertical launch into elliptical parking orbits.

i. Transearth.- The inclination and the time of flight of the transearth trajectory are used to control the reentry in such a way that the reentry track will be over existing network facilities and traverses reasonable recovery areas. Inclination appears to be in the range of from 30° to 35° which makes use of existing facilities and is compatible with landing site in Southern Texas, Hawaii, and Australia. The injection requirements for transfer from lunar orbit to the transearth trajectory are nearly the same as those for establishing lunar orbits shown in figure 35. The nominal reentry for Apollo missions is to be with posigrade motion with respect to the earth to reduce the reentry heating and widen the reentry corridor.

[redacted]

j. Reentry - The 10g reentry corridor for L/D=0.5 is 40 N.M. for an ARDC-1959 standard atmospheres. The effects of atmospheric variation reduce the reentry corridor to about 35 N.M.. Losses due to reentry control techniques which do not use negative lift amount to about 5 N.M.. The maximum reentry corridor for Apollo missions for 10 g maximum deceleration is 30 N.M.

The location of the reentry point is determined by the declination of the moon at the time the trans-earth trajectory is initiated, the transit time, and the inclination of the return orbit.

The locus of reentry points for a landing site in Southern Texas and in Australia is shown in figure 48 for several lunar declinations. The track of a 30° reentry orbit indicates that a range after reentry of 7,000 to 8,000 miles is required to return to the Southern Texas for reentry at all lunar declinations. The use of a second landing site in Australia would reduce the maximum required reentry range to about 5,300 nautical miles. Return would be to Texas for Southern declination of the moon and to Australia for Northern declinations of the moon. A typical reentry from a lunar mission for landing in Southern Texas is shown in figure 48 along with the landing areas, possibly with an L/D = 0.5 vehicle.

3.3.4 Example Flight Plan. - The flight plan presented is an example and does not represent design criteria.

a. Lift-Off Conditions - The launch azimuth is 91°.

b. Lift-Off to Parking Orbit - The characteristics of the flight plan from launch to insertion into a parking orbit at an altitude of 600,000 feet are presented in figures 49a and 49b.

c. Parking Orbit - Ground tracks for the initial earth orbit having a launch azimuth of 91° are presented in figure 50. The parking orbit is circular at an altitude of 600,000 feet. The only portion of the Continental United States over which the Spacecraft passes during the first revolution is Southern Texas.

d. Parking Orbit to Translunar - The location of the beginning of the insertion phase may be anywhere along the parking orbit depending upon the moon's declination. Figure 50 shows earth tracks for an insertion location in the mid-Pacific region. The characteristics of the flight plan from the parking orbit to the translunar trajectory are presented in figure 51.

e. Translunar and Transearth - Figure 52 presents the translunar and transearth trajectories for the inertial earth-moon system. The translunar trajectory has the characteristic that if no velocity increment is applied, the Spacecraft will return to earth at acceptable reentry conditions. The pericynthion altitude at the moon is 600,000 feet. The return or transearth trajectory shown in figure 53 represents a continuation of the translunar trajectory with a break of 25 hours for landing on the moon and take-off. The transearth and translunar trajectories combined form a reference circumlunar trajectory with proper correction for the lunar time break.

f. Lunar Orbit. - The velocity increment required to place the Spacecraft in a 100 nautical-mile circular equatorial lunar orbit from the approach pericynthion altitude of 100 nautical miles is seen to be 3415 ft/sec. The landing site is surveyed as the Spacecraft passes over this area during its first revolution. As the Spacecraft approaches a point 180° from the landing site, the Lunar Excursion Module and crew will be separated from the Command Module to await transfer to an elliptical orbit. As the Spacecraft approaches a point 90° from the landing site, the Lunar Excursion Module propulsion system shall be capable of providing a velocity impulse of 655 ft/sec to attain the desired elliptical orbit with a pericynthion altitude of 50,000 feet (this includes a 5° plane change).

g. Lunar Landing - The lunar landing maneuver is initiated at approximately 50,000 feet altitude. The characteristics of the flight plan during this maneuver are presented in Figure 54. The maneuver ends at an altitude of 350 feet at which time the Lunar Excursion Module vertical and horizontal velocity are near zero. The Lunar Excursion Module shall have the capability to hover at this altitude and translate 1000 feet for a time of two minutes. The velocity impulse required to perform these maneuvers is 7243 ft/sec.

h. Lunar Launch - The characteristics of the flight plan from lunar take-off to insertion into the elliptical parking orbit are presented in Figure 55. Transfer of the Lunar Excursion Module from its elliptical orbit to Command/Service Module circular orbit will be accomplished by the Lunar Excursion Module propulsion system. The Lunar Excursion Module propulsion system shall be capable of producing a velocity impulse of 6395 ft/sec to accomplish this phase (this includes 5° plane change maneuver).

i. Rendezvous and Docking - The rendezvous and docking maneuvers will be accomplished by the Lunar Excursion Module with the Command/Service Module taking corrective action as backup to the Lunar Excursion Module guidance and propulsion systems. A velocity impulse capability of 600 ft/sec will be required for completion of rendezvous and docking.

j. Launch from Lunar Orbit - The transfer from the 100 nautical mile circular orbit to insertion into the transearth trajectory is accomplished by the application of a velocity increment of 4097 ft/sec at the insertion. This velocity increment is provided by the Service Module propulsion system.

k. Transearth - The transearth trajectory is presented in figure 53.

l. Reentry - The return perigee altitude is 120,000 feet, the velocity at perigee is 36,320 ft/sec, and the reference reentry altitude is 400,000 feet. The time at which the reentry altitude is reached is 4:00 p.m. local time, for the primary flight plan of 167 hours after launch. A ground track of the transearth and reentry phase of the flight plan is shown in figure 53. The possible landing area extends from the Western Pacific across the Southern United States and into the South Atlantic. The characteristics of the Spacecraft during reentry are for an L/D ratio of .5 and a W/C_DA of 50. The characteristics of the flight plan during reentry are presented in figure 56.

3.4 SPACECRAFT SYSTEMS. - A description of the characteristics of the Spacecraft and its systems is presented in this section.

3.4.1 Spacecraft Configuration. - The physical relationship of Spacecraft Modules and major components is specified graphically by schematics with identifying notes. Precise arrangements and detailed mechanical features are not intended to be inferred by the figures.

3.4.1.1 General Arrangement. - The Spacecraft arrangement for lunar landing missions is shown in figure 57.

3.4.1.2 Mission Arrangements. - Spacecraft arrangements for the various missions up through lunar landing are shown in figures 58, 59, 60, and 61. These arrangements demonstrate system buildup and off-loading techniques convenient to component development and Launch Vehicle capabilities.

3.4.1.3 Command Module. - The Command Module physical features are defined by aerodynamic and heating performance requirements and crew utility and well-being considerations.

3.4.1.3.1 Geometric Characteristics. - The basic external geometry of the Command Module is shown in figure 62. The Command Module shall be a symmetrical, blunt body developing a hypersonic L/D of approximately 0.50. The L/D vector shall be effectively modulated in hypersonic flight. The modulation is achieved through constant c.g. offset and roll control.

3.4.1.3.2 Inboard Profile. - Basic arrangements of internal features fundamental to full utilization of the Command Module geometry are shown in figures 63, 64, 65, and 66.

3.4.1.3.2.1 Load Mitigation Swept Volume. - The crew is suspended on discrete load mitigation devices which normally act on earth-landing impact. The swept volume displayed by this load mitigation stroke is significant and is to be recognized in the internal layout.

3.4.1.3.2.2 Crew Space Equipment. - Crew space equipment shall be free of protrusions and snags.

3.4.1.3.2.3 Center-of-Gravity Management. - Consideration shall be given to the arrangement of water stores to permit center-of-gravity management. Alteration of crew positions may be used for center-of-gravity management where orientation with respect to displays and controls is not limited.

3.4.1.3.2.4 Center Aisle. - The center crew support equipment is readily removable and stowable. This provides a center aisle which is required to make full use of the volume and give ready access to all regions.

3.4.1.3.2.5 Air Lock Operation. - An air lock is extended into the center aisle region for transient conditions and allows exit or egress to or from the Command Module in the environment of space from either side. See figure 63.

3.4.1.3.2.6 Head Room. - Ground and flight crews performing maintenance, repair and checkout tasks have good head room resulting in an efficient operation. See figure 63.

3.4.1.3.2.7 Stations. - A variety of crew station combinations are obtained using various arrangements of individual stations. See figure 63.

3.4.1.3.2.7.1 Left Hand Station. - The left hand station is to be semi-permanently fixed in the near launch condition. Capabilities for movements to better utilize displays and to achieve comfort are to be provided. Access to equipment on the outboard side is achieved by a movement capability which uncovers the area of concern.

3.4.1.3.2.7.2 Center Station. - The center station is stowable and may be replaced by many combinations of crew orientation during flight.

3.2.1.3.2.7.3 Right Hand Station. - The right hand station can have the same capabilities as the left hand station or it can be stowed as is the center station depending on mission requirements.

3.4.1.3.2.8 Visibility. - A broad field of view is provided by windows over the crew's heads in the launch condition. These windows are covered by heat protection elements during launch, reentry and general flare activity at the descretion of the crew.

3.4.1.3.2.9 Access and Egress Hatches. - Three outward opening hatches are provided in the Command Module just above the crew's heads. The windows for broad field of view are incorporated in these hatches. All hatches are used for ground access, servicing and maintenance. The three hatches provide the crew with individual bailout or other types of emergency egress without interfering with each other's activity. Normal access and egress for crew and all onboard equipment installation is achieved through the use of the large center hatch.

3.4.1.3.2.10 Earth Landing System. - The Earth Landing System is stowed in the upper portion of the afterbody. See figure 66.

3.4.1.3.2.11 Reaction Control. - The tankages and other impact sensitive elements for the Reaction Control System are stowed out of the nominal impact area. See figure 66.

3.4.1.3.2.12 Load Mitigation. - The nominal impact area is provided with load mitigation structure which absorbs the initial energy of impact for the Command Module. See figure 66.

3.4.1.4 Spacecraft Adapter. - The method of attachment, basic structure and external geometry with the exception of length shall be identical between Spacecraft Adapters for all mission configurations. The adapter structure shall be compatible with the adjoining modules and propulsion stages. Its overall bending stiffness shall satisfy the requirements of the Launch Vehicle. Its construction shall be buffet and noise resistent in atmospheric phase of flight.

3.4.1.5 Lunar Excursion Module. - The Lunar Excursion Module general landing configuration is shown in figure 67.

3.4.1.5.1 Stowed Configuration. - The Lunar Excursion Module is stowed in the adapter region, and the landing gear is stowed extended aft.

3.4.1.5.2 Access. - Free access to the Lunar Excursion Module upper cabin region shall be provided through panels in the adapter opposite the Lunar Excursion Module access hatch. Free access shall also be provided to the Lunar Excursion Module lower propulsion, equipment and landing gear region through panels in the lower region of the spacecraft adapter.

3.4.1.5.3 Initial Positioning Configuration. - The Lunar Excursion Module shall be repositioned from its stowed position in the Spacecraft Adapter to a docked position with the Command Module prior to the first midcourse correction. This can be accomplished by either the Service Module reaction control system maneuver the Command/Service

Module combination to a docked position or a mechanical system positioning the Lunar Excursion Module to the docked position. The general docking arrangement is shown in figure 68.

3.4.1.5.4 Translunar Configuration. - The Spacecraft configuration for the translunar flight and up to separation of the Lunar Excursion Module in lunar orbit for the lunar landing mission is shown in figure 68. Provisions should be made for remotely deploying the landing gear.

3.4.2 **Command and Service Modules Systems.** - The characteristics of the major systems included in the Command and Service Modules are presented. Similar systems for the Lunar Excursion Module are subsequently discussed in Section 3.4.3.

3.4.2.1 **Guidance and Control System.** - The Guidance and Control System is comprised of a Guidance and Navigation System and a Stabilization and Control System. The stabilization and Control System provides the attitude stabilization and maneuver control requirements for the Spacecraft and for combinations of Spacecraft and appropriate Propulsion Modules. The Guidance and Navigation System provides steering and thrust control signals for the Stabilization and Control System, Reaction Control Systems, and appropriate propulsion system and their respective gimbal systems.

3.4.2.1.1 **Navigation and Guidance System.** -

3.4.2.1.1.1 **Functional Requirements.** - The functional requirements of the Navigation and Guidance System are presented below.

3.4.2.1.1.1.1 **Space Vehicle Guidance.** - The Navigation and Guidance System shall be capable of controlling the injection of the Spacecraft and of providing a monitoring capability of injection guidance to the crew. This shall be accomplished for both direct ascent and for injection from a parking orbit.

3.4.2.1.1.1.2 **Midcourse Guidance.** - The Navigation and Guidance System shall provide navigation data and compute velocity corrections in ciscular space to achieve terminal conditions at the moon and earth which allow a safe lunar landing and earth reentry, respectively. Enroute to the moon a mission abort capability shall be provided.

3.4.2.1.1.1.3 **Reentry Guidance.** - The Navigation and Guidance System shall be capable of guiding the Command Module during reentry through the earth's atmosphere to a preselected landing site on the earth. This capability shall be provided for reentry from lunar missions and earth orbits, from preinjection aborts, and from postinjection aborts.

3.4.2.1.1.1.4 **Lunar Orbit.** - The Navigation and Guidance System shall provide a capability for establishing lunar orbits.

3.4.2.1.1.1.5 Rendezvous. - The Navigation and Guidance System shall be capable of accomplishing a rendezvous in lunar orbit between the spacecraft and the Lunar Excursion Module.

3.4.2.1.1.2 System Description. - The system shall achieve simplicity and reliability by effectively employing the crew whenever equipment design advantage and crew capability are compatible. The system shall achieve operational versatility but, when versatility results in disproportionate increase in equipment complexity, onboard versatility shall be sacrificed and reliance shall be placed upon ground assistance. The system shall be reliable but reliability shall be obtained by the use of system or subsystem redundancy only if it cannot be obtained by ground cooperation and/or onboard emergency systems.

3.4.2.1.1.3 Subsystems. - Subsystems which have been clearly identified are the following:

Inertial platform
Space sextant
Computer
Controls and displays
Electronics assembly
Charts and star catalog

In addition to the above, there are requirements for range and/or velocity measuring equipment for terminal control in rendezvous. These may require either radar or visual range-finding equipment or both. There are also requirements for backup inertial components for emergency operation.

3.4.2.1.2 Stabilization and Control System. - The functional requirements and a description of the Stabilization and Control System are presented below.

3.4.2.1.2.1 Requirements. - The system shall satisfy the following requirements.

3.4.2.1.2.1.1 Atmospheric Abort. - Flight-path control during the thrusting period of atmospheric abort and stability augmentation after Launch Escape Propulsion System separation.

3.4.2.1.2.1.2 Extra-Atmospheric Abort. - Orientation, altitude control, and reentry stabilization and control. The system shall accept commands from the guidance system for thrust vector control and reentry control.

3.4.2.1.2.1.3 Parking Orbit. - Stabilization of the Spacecraft while in a parking orbit.

3.4.2.1.2.1.4 Translunar and Transearth. - Stabilization and control during midcourse flight both outbound and inbound. The control technique shall provide fuel economy and shall satisfy all navigation requirements as well as solar orientation and antenna-pointing requirements. Attitude control and orientation for application of midcourse corrections shall be provided.

3.4.2.1.2.1.5 Lunar Orbit. - Stabilization and control during lunar orbit.

3.4.2.1.2.1.6 Orbital Rendezvous and Docking. - Stabilization and control of the Command and Service Module during rendezvous and "docking" with the Lunar Excursion Module.

3.4.2.1.2.1.7 Reentry. - Control requirements for reentry guidance. Reaction jets will be employed for three-axis stabilization. Reentry control will be provided by rolling the vehicle which is trimmed at an L/D.

3.4.2.1.2.1.8 Earth Landing. - Stabilizing and controlling the Command Module with respect to the flight direction in the earth landing configuration. Command control will be by the crew employing visual reference.

3.4.2.1.2.1.9 Special Control Features. - Consideration shall be given to meeting a requirement for fine control of Spacecraft rolling response to tracking control commands from the Guidance and Navigation Systems. Consideration shall also be given to methods for optimizing overall system design for midcourse flight by integrating requirements for Spacecraft three-axis control and antenna-pointing requirements.

3.4.2.1.2.2 System Description. - The Stabilization and Control System shall consist of the following basic components:

Attitude reference
Rate sensors
Control electronics assembly
Manual controls
Attitude and rate displays
Power supplies

3.4.2.1.2.2.1 Attitude Reference. - The attitude reference system provides angular displacement signals to the Stabilization and Control System and instrument panel displays. The primary reference system is provided within the Guidance and Navigation System. Requirements for additional special attitude sensors are not specified at this time. Some examples of these requirements follow.

3.4.2.1.2.2.1.1 Standby Inertial Reference. - A standby reference which is capable of retaining an inertial reference throughout any combination of Spacecraft maneuver. This system may be erected by the primary reference system but it must be capable of having erected to an inertial reference independent of the primary navigation system. It should also be capable of driving panel displays.

3.4.2.1.2.2.1.2 Special Sensors. - Non-gyroscopic sensors are required for solar orientation during midcourse flight and for third-axis control in connection with antenna-pointing requirements. Consideration should be given to the use of the outputs of these sensors to control directly through the switching logic of the electronic assembly and to the use of derived rate from the sensor output.

3.4.2.1.2.2.2 Rate Sensors. - Three axes rate gyro packages shall provide stability augmentation during propulsion modes, maneuvers and reentry. They also serve as a necessary sensor for the Rate Command System and require a dynamic range capable of dealing with all vehicle configurations and mission requirements. Redundancy shall be provided compatible with the overall system configuration.

3.4.2.1.2.2.3 Control Electronics Assembly. - The Stabilization and Control System Control Electronics Assembly shall accept command inputs from the Navigation and Guidance System during periods of thrust vector control, periods of tracking for navigation purposes, and from the Stabilization and Control System attitude reference at all other times. The Control Electronics Assembly shall supply thrust command signals to the attitude control propulsion motors to establish correct orientation, stable limit cycle operation, and damping throughout all phases of the mission. The control electronics shall use pulse modulation of similar techniques by which the desired objectives of economical limit cycling, accurate control during periods of large disturbances, and satisfactory maneuver rates can all be achieved with the same switching logic. Flexibility to deal with all vehicle configurations and mission requirements shall be attained by the provision of adjustments for parameters such as attitude dead band, rate limits, and attitude to rate gain. To ease the control task of the pilot, the system must be capable of accepting discrete "dialed" orientation commands or provide an attitude followup for reengagement of attitude hold when the maneuver is completed. The control electronics shall be of modular construction and provide the necessary redundancy and inflight maintenance capability.

3.4.2.1.2.2.4 Manual Control. - The suggested method of maneuvering by the pilot is by opening the outer loop and imposing rate commands on the inner rate stabilization loop. The manual controls shall be capable of operating all reaction control motors by direct electrical connection, providing emergency operation in case of rate gyro or other automatic system failure. Design of the controls shall provide acceptable feel characteristics for all conditions of flight environment. Provision for the translational control by the crew for docking and hovering phases of the mission shall be compatible with the attitude control system concept.

3.4.2.1.2.2.5 Attitude and Rate Displays. - Angular rates and vehicle attitudes with respect to the reference shall be displayed during manual maneuvering and critical phases of the mission. At all other times, displays shall be commensurate with crew requirements.

3.4.2.1.2.2.6 Power Supplies. - The Stabilization and Control System shall generate all levels of DC and AC voltage requirements internally from the basic vehicle electrical supply. Choice of operating frequencies and provision of redundancy in the power supplies shall be governed by the requirements for compatibility between Navigation and Guidance and Stabilization and Control Systems.

3.4.2.2 Service Propulsion System.-

3.4.2.2.1 General Description.- The Apollo Service Propulsion System will be located in the Service Module and be capable of meeting the requirements for:

a. Abort propulsion after jettison of Launch Escape Propulsion System.

b. All major velocity increments and midcourse velocity corrections for missions prior to lunar landing mission.

c. All major velocity increments required for trans-lunar midcourse velocity corrections, placing the Spacecraft into a lunar orbit, for rendezvous the Command/Service Module with the Lunar Excursion on a back-up mode, for transfer of the Command/Service Module from lunar orbit to insertion into the trans-earth trajectory, and transearth midcourse velocity correction for lunar landing missions.

A suggested single engine schematic configuration is shown in figure 69. The Service Propulsion System will utilize earth-storable, hypergolic propellants, will include single or multiple thrust chambers with a thrust-to-weight ratio of at least 0.4 for all chambers operating, (based on the lunar launch configuration), and will have a pressurized propellant feed system.

3.4.2.2.2 Performance Requirements.-The Service Propulsion System will be required to function in several normal and emergency modes, depending upon the mission for which it is being used.

3.4.2.2.2.1 Earth Orbit Mission.-

3.4.2.2.2.1.1 Earth-Orbital Retrograde Velocity.-A retrograde velocity is required to reenter the Spacecraft from earth-orbital mode.

3.4.2.2.2.1.2 Earth Orbital Corrections.-A velocity increment is required to correct earth-orbit after insertion by Launch Vehicle.

3.4.2.2.2.1.3 Post-Atmospheric Abort.-Mission abort during post-atmospheric portion of launch trajectory will be accomplished by the Service Propulsion System. As the Launch Escape Propulsion System is to be jettisoned shortly after escape from the atmosphere, the Service Propulsion System will be utilized for velocity increment as required to provide separation from the Launch Vehicle, reentry control, and landing point selection if required.

3.4.2.2.2.2 Circumlunar Mission.-

3.4.2.2.2.2.1 Midcourse Velocity Corrections.-The mission trajectory selected will influence the magnitude of midcourse velocity corrections required for this mission. The Service Propulsion System will supply gross velocity increments not supplied by the Reaction Control System.

3.4.2.2.2.2.2 Launch Abort at Sub-Orbital Velocities.-Mission abort during post-atmospheric portion of launch trajectory will be accomplished by the Service Propulsion System. After the Launch Escape Propulsion System is jettisoned, the Service Propulsion System will be utilized for velocity increment as required to provide separation from the Launch Vehicle, reentry control, and landing point selection if required.

3.4.2.2.2.2.3 Launch Abort at Super-Orbital Velocities.-A velocity increment is required to separate the Spacecraft from the Launch Vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

3.4.2.2.2.3 Lunar Orbit Missions.-

3.4.2.2.2.3.1 Midcourse Velocity Corrections.-The mission trajectory selected will influence the magnitude of midcourse velocity corrections required for this mission. The Service Propulsion System will supply gross velocity increments not supplied by the Reaction Control System.

3.4.2.2.2.3.2 Lunar Capture.-In the vicinity of the moon the Service Propulsion System will supply velocity increment as required for insertion into lunar orbit from a free-return, circumlunar trajectory 5° out of the plane of the lunar orbit.

3.4.2.2.2.3.3 Lunar Orbit Transfer.-The velocity increment is as required to transfer from a circular to elliptical lunar orbit.

3.4.2.2.2.3.4 Lunar Escape Velocity.-The velocity increment is as required for lunar-orbit escape and earth return.

3.4.2.2.2.3.5 Post-Atmospheric Abort.-Mission abort during post-atmospheric portion of launch trajectory will be accomplished by the Service Propulsion System. After the Launch Escape Propulsion System is jettisoned the Service Propulsion System will be utilized for velocity increment as required to provide separation from the Launch Vehicle, reentry control, and landing point selection if required.

3.4.2.2.2.3.6 Super-Orbital Abort.-The velocity increment is as required to separate the Spacecraft from the Launch Vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

3.4.2.2.2.3.7 Post-Injection Abort.-The velocity increment is as required to separate the Spacecraft from the Launch Vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

3.4.2.2.2.4 Lunar Landing Mission.-

3.4.2.2.2.4.1 Midcourse Velocity Correction.-The mission trajectory selected will influence the magnitude of midcourse velocity corrections required for this mission. The Service Propulsion System will supply gross velocity increments not supplied by the Reaction Control System.

3.4.2.2.2.4.2 Lunar Capture.-In the vicinity of the moon the Service Propulsion System will supply velocity increments as required for insertion into lunar orbit from a free-return circumlunar trajectory 5° out of the plane of the lunar orbit.

3.4.2.2.2.4.3 Lunar Escape Velocity.-The velocity increment is as required for lunar-orbit escape and earth return.

3.4.2.2.2.4.4 Post-Atmospheric Abort.-Mission abort during post-atmospheric portion of launch trajectory will be accomplished by the Service Propulsion System. After the Launch Escape Propulsion System is jettisoned, the Service Propulsion System will be utilized for velocity increment as required to provide separation from the launch vehicle, reentry control, and landing point selection as required.

3.4.2.2.2.4.5 Super-Orbital Abort.-The velocity increment is as required to separate the Spacecraft from the Launch Vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

3.4.2.2.2.4.6 Post-Injection Abort.-The velocity increment is as required to separate the Spacecraft Command and Service Modules from the launch vehicle and to reorient the total velocity vector such as to allow early reentry or safe orbital stabilization.

3.4.2.2.3 System Operation.-

3.4.2.2.3.1 Operating Features.-Helium tanks shall be positively sealed by redundant valves prior to use to prevent leakage. Primary and secondary propellant pressurization regulators are required. Propellant utilization control is required to maintain proper oxidizer/fuel ratio. This may be accomplished through regulating either oxidizer or fuel flow rates. It is desirable to minimize the number of valves required to open to obtain ignition. Propellant utilization control should provide for primary and secondary mode of operation. If multiple oxidizer and fuel tanks are used, cross ties to allow use of primary or secondary controls with any tank of the regulated fluid (oxidizer or fuel) shall be provided. Isolation valves shall be provided in these tie lines. If multiple fuel and oxidizer tanks are used, each tank should be emptied prior to use of next tank. Automatic switch over from tank to tank with manual override is required. Propellant for large velocity requirements such as lunar launch and lunar escape shall be fed from the main propellant tanks. Propellant for small velocity requirements such as mid-course corrections will be fed from positive expulsion tanks common with the Service Reaction Control System or auxiliary positive expulsion tanks.

3.4.2.2.3.2 Safety Features.-Filters to protect regulators, control valves, and propellant injectors are required. Check valves to prevent oxidizer-fuel cross flow shall be provided in pressurization lines. There shall be relief valves to relieve high propellant tank pressures. Burst discs shall protect relief valves from propellant contamination. Redundant propellant valves are required. Manual override provisions on automatic solenoid valves and control valves shall be required. Helium and propellant tanks are to be sealed prior to use. Maximum use of welded or brazed lines and fittings to minimize leak points is desirable. Modular concept of replacement of subsystems is desirable.

3.4.2.2.3.3 Preflight Checkout.-Fittings are to be provided to gas leak check and purge all parts of the system and to flow check all regulators and control valves and to check normal and emergency valve sequences. Provisions for checking gimballing system prior to operation shall be required. Provisions for checks of all sensors and instrumentation required. Means for cleaning or replacement of system filters prior to flight shall be provided. System shall be static-fired as an entire system prior to flight, preferably in the lunar launch configuration including Command Module and other Service Module systems.

3.4.2.2.4 Crew Participation (Displays and Control). -

3.4.2.2.4.1 Monitoring Function. - During flight and non-operating periods the crew shall monitor tank pressures, leakage rates, and temperatures. Instrumentation of these items is therefore required. During engine operation, crew shall be able to monitor such system operating parameters as propellant and helium pressures, chamber pressure, and temperatures. Prior to and during engine operation, the crew shall be able to monitor engine gimbal operation. Crew shall be able to monitor all engine valving position. Remaining quantities of oxidizer and fuel shall be presented to crew during operation. Some means of indicating reserve propellant remaining and propellant utilization system operation are desired.

3.4.2.2.4.2 Normal Operation. - Preparation of system for engine ignition shall be a crew function. Actual firing shall be an automatic function performed by the guidance system. Crew shall be able to monitor the automatic function. Crew shall be able to monitor automatic switchover function from one oxidizer or fuel tank to another provided multiple tanks are used.

3.4.2.2.4.3 Emergency Operation. - There shall be a means provided to automatically and/or manually initiate system operation for abort capability in event of booster failure. Automatic engine shutdown of redundant engines in event of low chamber pressure, high external temperatures indicating external fire or other engine failures shall be provided. Automatic switchover to redundant regulator in event of helium primary regulator failure in the open mode is required to prevent helium loss. If multiple oxidizer and fuel tanks are used, manual override of automatic tank switching device shall be provided. Crew shall be able to manually shutdown the engine or engines and shall be able to manually override any automatic function. Provisions for in-flight, extra-vehicular access by crew for inspection, and maintenance shall be provided.

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3.4.2.2.5 Guidance System Requirements. -

3.4.2.2.5.1 Thrust-Vector Control. - This system shall be designed to control the thrust-vector during midcourse velocity corrections with frequent restart capability. The gimbal actuators shall be redundant for this engine. These actuators shall have the necessary response characteristics to maintain proper trajectories.

3.4.2.2.5.2 Velocity Cut-off Control. - This system shall be designed to control the velocity-cut-off during midcourse velocity corrections. The valve closing times should be held within limits to prevent damage from hydraulic hammer effect. Engine surge characteristics shall be investigated for different valve designs. Engine cut-off impulse accuracy shall be known within 2% of that required for the minimum operating cycle. The magnitude of impulse error shall not exceed 150 lb-sec.

3.4.2.2.6 Propellants. - The Service Propulsion System shall use an earth storable hypergolic bipropellant combination.

3.4.2.2.6.1 Oxidizer. - The oxidizer shall be nitrogen tetroxide (N_2O_4) with nitrous oxide (N_2O) added to depress the freezing point if necessary.

3.4.2.2.6.2 Fuel. - The fuel shall be either monomethylhydrazine (MMH) or a mixture of 50% hydrazine (N_2H_4) and 50% unsymmetrical dimethylhydrazine (UDMH).

3.4.2.2.7 Component Selection. - The example schematic shows a single thrust chamber. The schematic indicates the essential components and their functional interelationship.

3.4.2.2.7.1 Tanks. - Toroidal tanks shall not be used with multiple thrust chambers.

3.4.2.2.7.2 Pressurization. - Ambiently stored helium gas shall be used for pressurization. Tanks shall be held to minimum consonant with packaging requirements.

3.4.2.2.7.3 Control Systems. -

3.4.2.2.7.3.1 Thrust Vector Control. - Thrust vector control shall be attained by redundant gimballing. Electromechanical and electrohydraulic systems should be compared.

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3.4.2.2.7.3.2 Liquid Level Sensing System. - A liquid level sensing system is required to indicate propellant level in the tanks during periods of acceleration so that the crew can check propellants available.

3.4.2.2.7.3.3 Propellant Utilization System. - A propellant utilization system shall be supplied to ensure efficient utilization of propellant.

3.4.2.2.7.4 Performance. - The minimum delivered vacuum specific impulse shall be 315 $\frac{\text{lb-sec.}}{\text{lb.}}$

3.4.2.3 Reaction Control System. - The Command and Service Modules shall include Reaction Control Systems to provide the impulse for attitude control and stabilization. The Service Module System shall also be capable of minor translational velocity increments.

3.4.2.3.1 Command Module Reaction Control System. - This system will be used only after separation of the Command Module from the Service Module.

3.4.2.3.1.1 Requirements. - The system shall provide three-axis control prior to the development of aerodynamic moments, roll control during reentry and landing, and pitch and yaw rate damping during reentry and deployment of the landing system. A roll acceleration of at least 10°/sec/sec shall be provided during reentry. The pitch and yaw acceleration shall be compatible with their requirements.

3.4.2.3.1.2 Description. -

3.4.2.3.1.2.1 General. - The suggested Reaction Control System is pulse modulated, pressure fed, and utilizes earth storable hypergolic fuel. Fuel tanks shall be positive-expulsion type. The Command Module has two independent systems as shown in figure 70 and located as shown in figure 71. Each is capable of meeting the total torque and propellant storage requirements. Each system consists of helium pressurization, propellant storage, distribution and thrust chamber subsystems.

3.4.2.3.1.2.2 Propellants. - The Reaction Control System shall use an earth storable hypergolic bipropellant combination.

3.4.2.3.1.2.2.1 Oxidizer. - The oxidizer shall be nitrogen tetroxide (N_2O_4) with nit ous oxide (N_2O) added to depress the freezing point if necessary.

3.4.2.3.1.2.2.2 Fuel. - The fuel shall be either monomethylhydrazine (MMH) or a mixture of 50% hydrazine (N_2H_4) and 50% unsymmetrical dimethylhydrazine (UDMH).

3.4.2.3.1.2.3 Distribution. - Each system shall consist of six thrust chamber subystems installed to provide six degrees of control as shown in figure 70. Either system shall be capable of remote isolation by the crew by means of reversible valves.

3.4.2.3.1.2.4 Thrust Chambers.- Since the chambers and nozzles must be buried within the module, they should be ablatively cooled. Alternate methods may be considered which would also maintain compatible external temperatures on the units. Heat protection of control valves shall be provided if necessary.

3.4.2.3.1.3 Operation.-

3.4.2.3.1.3.1 Servicing and Checkout.- Each system shall be designed to allow preflight servicing, checkout, and deactivation.

3.4.2.3.1.3.2 Flight.- The systems shall be designed to operate simultaneously from the crew manual controls by means of electrical outputs. Malfunction detection means should be investigated which would allow for shutdown of one system if a thruster in that system fails.

3.4.2.3.2 Service Module Reaction Control System.- This system will provide the impulse for attitude control and stabilization for the Space Vehicle in all phases of flight except during periods that other propulsion systems are active. In addition, the system shall provide attitude control and stabilization for the Launch Vehicle Spacecraft combination in earth parking orbit. The system shall also provide minor translational capability for minor midcourse corrections, terminal rendezvous and docking as well as ullage accelerations for Service Propulsion System, if necessary. The system shall contain the flexibility required to allow its use in all missions.

3.4.2.3.2.1 Requirements.- The final requirements for the system will be coordinated with the Contractor as they become available. A preliminary estimate indicates that 400 pounds of propellant including 30 percent reserve will be adequate for all missions, provided a minimum pulse not to exceed 20 milliseconds with a 90 percent pulse efficiency is attained.

3.4.2.3.2.2 Description.-

3.4.2.3.2.2.1 General.- The Reaction Control System is pulse modulated, pressure fed, and utilizes earth-storable hypergolic fuel. Fuel tanks shall be positive-expulsion type. The suggested Service Module Reaction Control system has two independent systems as shown in figure 72 and located as shown in figure 73. Each is capable of meeting the total torque and propellant storage requirements. The system shall consist of 8 roll, 4 pitch and 4 yaw, thrust chamber subsystems. It shall be designed to allow translation in six directions. The system has two sets of propellant tanks and pressurization subsystems. The thrust shall be installed so that normal translational thrust vectors are in the vicinity of the vehicle center of gravity for the earth-orbiting mission. The roll thrusters will be used for pitch and yaw maneuvering whenever the Lunar Excursion Module is attached. Each set of tanks supplies six small thrust chambers capable of control in all 6 directions during navigational sightings.

3.4.2.3.2.2.2 Propellant.- The propellants shall be the same as those used for the Service Propulsion System.

3.4.2.3.2.2.3 Distribution.- Each set of tanks normally supply one thruster of each couple and the feed systems from the two sets of tanks are normally isolated. Figure 72 shows a system utilizing positive expulsion tanks. The method of storage must satisfy Reaction Control and minor mission velocity requirements. Each set of thruster chambers is capable of being isolated by the crew.

3.4.2.3.2.2.4 Thrust Chambers.- An intensive program should be undertaken to develop and evaluate both the radiation-cooled and ablation-cooled thrust chambers for this application. Particular attention should be given to the effects of intermittent firing of the chambers in a hard vacuum.

3.4.2.3.2.3 Operations.-

3.4.2.3.2.3.1 Servicing and Checkout.- Each system shall be designed to allow preflight servicing, checkout, and de-activation.

3.4.2.3.2.3.2 Flight.- The system shall be designed to operate from manual-electric and automatic-electric input signals. A major effort is required in order to develop satisfactory means for malfunction detection in the system especially in the area of small leakage rates.

3.4.2.4 Launch Escape System.- The Command Module shall be fitted with a Launch Escape System as shown in figure 57.

3.4.2.4.1 Requirements.- The Launch Escape Propulsion System separates the Command Module from the Launch Vehicle in the event of failure or imminent failure of the Launch Vehicle during all atmospheric phases. The performance of the Launch Escape Propulsion System is dictated by the requirements of crew response and/or of the Abort Sensing Implementation System of the Launch Vehicle and the structural capability of the Command Module to resist overpressures due to Launch Vehicle explosion. Two critical flight modes are recognized.

3.4.2.4.1.1 Pad Escape.- For escape prior to or shortly after lift-off, the Launch Escape Propulsion System separates the Command Module from the Launch Vehicle and propels the Command Module to an altitude of at least 5000 feet and a lateral range at touchdown of at least 3000 feet without exceeding the crew tolerances. Stabilization and lateral control, if required, shall be provided.

3.4.2.4.1.2 Maximum Dynamic Pressure Escape.- For escape at maximum dynamic pressure, the Launch Escape Propulsion System separates the Command Module from the Launch Vehicle during thrusting of the Launch Vehicle and propels the Command Module a safe distance from the Launch Vehicle. The Launch Escape Propulsion System and the Command Module combination are aerodynamically stable or neutrally stable and have sufficient lateral control to obtain the maximum possible Launch Vehicle "miss" distance consonant with the crew tolerances.

3.4.2.4.2 Propulsion.- The basic propulsion system is a solid-fuel rocket motor with "step" or regressive burning characteristics. Its nozzles are canted to avoid direct impingement of the exhaust jets on the Command Module.

3.4.2.4.3 Stabilization and Control.- Stabilization and lateral control shall be provided.

3.4.2.4.4 Escape System Jettison.- The Launch Escape Propulsion System is jettisoned at approximately maximum altitude after "pad escape," or an appropriate time after high dynamic pressure escape, and is separated from the Command Module by a solid-fuel rocket motor. For normal flights, separation is effected by the main propulsion motor during early operation of the second stage of the Launch Vehicle.

3.4.2.4.5 Initiation and Control Mode Selection.- Initiation of escape and subsequent selection of control modes is the responsibility of the crew. There shall be no responsibility assigned to ground control or automatic systems unless there is insufficient time and/or information for crew action.

3.4.2.5 Earth Landing System. - The Command Module includes an Earth Landing System to be used under all flight conditions for earth landing requirements.

3.4.2.5.1 Requirements. - The system satisfies the following requirements after normal reentry, maximum dynamic pressure escape, and pad escape.

3.4.2.5.1.1 Postentry Stabilization. - Stabilizes the Command Module during postentry descent.

3.4.2.5.1.2 Velocity Control. - Reduces the vertical touchdown velocity to not more than 30 feet per second at an altitude of 5000 feet.

3.4.2.5.1.3 Impact Attenuation. - Reduces impact acceleration such that neither the Command Module primary structure or flotation is impaired. Any further attenuation required by the crew shall be provided by individual, crewman shock-attenuation devices.

3.4.2.5.1.3.1 Impact Attitude. - For nominal land landings, the capsule should impact at an angle of -15^{o} with the c.g. forward. See figure 66. This locates the crew in a feet first position. For water landings an impact of 15^{o} with the c.g. aft and the crew located in head-first position is desirable. The maximum emergency limit "g" forces must not be exceeded for any landing regardless of capsule orientation.

3.4.2.5.1.4 Postlanding. - The system provides any necessary flotation, survival, and location aids.

3.4.2.5.2 Description. - The landing system consists of 2 FIST-type drogue chutes deployed by mortar and a cluster of three simultaneously deployed landing parachutes. Landing parachutes are sized such that satisfactory operation of any two of the three will satisfy the vertical velocity requirement. The Command Module is hung in a canted position from the parachute risers and oriented through a roll control to favor impact attenuation.

3.4.2.5.3 Initiation and Control. - Initiation of all functions can be manually controlled. Command Module roll orientation prior to impact can be also manually controlled.

3.4.2.6 Structural System.- In addition to the fundamental load carrying structures, the Command and Service Modules Structural System shall include meteoroid protection, radiation protection inherent in the structure, and Passive Heat Protection Systems. Primary structures shall be designed and evaluated in accordance with standard aircraft practice with the exception that no structure shall require pressure stabilization.

3.4.2.6.1 Command Module.-

3.4.2.6.1.1 Reentry Thermal Protection.- The Command Module's external thermal protection shall utilize the planned degradation of suitably reinforced plastics. The forebody shall utilize a charring ablator capable of sustaining high surface temperatures and providing effective blockage of external heat fluxes. Adequate reinforcement of the shield shall be provided to ensure shield integrity and satisfactory performance through all phases of flight.

Afterbody heat protection shall also utilize planned material degradation but consideration should be given to providing protection which is better suited to the more moderate heat flux environment and thinner gauges of the afterbody.

Passive control of heat fluxes to the interior of the Command Module shall be utilized. Circulatory heat exchange system used only for internal cabin comfort control,

Egress hatches, windows, umbilicals, etc., shall be located on low heat flux regions of the Command Module when possible and shall be covered by doors fairing smoothly to the capsule contour.

The reinforced plastic shall be mounted on a relatively rigid brazed or welded sandwich construction support capable of withstanding temperatures considerably in excess of conventional bonding temperatures. The adhesive bond between the ablator and the sandwich support must be capable of withstanding the low temperatures during the space flight and shall not be subjected to temperatures during reentry beyond demonstrated state-of-the-art capabilities.

3.4.2.6.1.2 Pressure Vessel.- The pressure cabin will be separate from the thermal protection system and will consist of an aluminum shell with longerons to react the concentrated loads from the escape tower and parachute attachments, and act as edge members for windows and hatches. Consideration will be given to the venting of the space between the pressure cabin and thermal protection. Viewing ports will form an integral part of the exit hatch.

3.4.2.6.2 Service Module.- The Service Module shall consist of a sandwich shell compatible with the noise and buffet requirements and the meteorite penetration requirements. In addition, it should maintain structural continuity with adjoining modules and be compatible with the overall bending stiffness requirements of the Launch Vehicle.

3.4.2.7 Crew Systems.-

3.4.2.7.1 Flight Crew.-

3.4.2.7.1.1 Size and Number.- The flight crew shall consist of three men. The size of each crew member shall be between the 10th and 90th percentile as defined in reference.

3.4.2.7.1.2 Division of Duties.- Tasks shall be so apportioned as to make maximum utilization of all three crew members. During launch, entry, and similar critical mission phases, division of key tasks amongst the three crew members shall be as nearly equal as possible. Division of specific responsibilities shall be as follows:

3.4.2.7.1.2.1 Commander (Pilot).- He shall control the vehicle in manual or automatic mode, during all phases of the mission. He shall select, implement and monitor the modes of navigation and guidance. He shall monitor and control key areas of all systems during time critical periods. He shall occupy either the left or center couch during launch and reentry.

3.4.2.7.1.2.2 Co-Pilot.- The co-pilot shall be second in command of the vehicle. He shall support the commander as alternate pilot and navigator. During critical mission phases, he shall monitor certain critical parameters of the spacecraft and propulsion systems. He shall occupy either the left or center couch during launch and reentry.

3.4.2.7.1.2.3 Systems Engineer.- During critical mission phases he shall monitor certain critical parameters of the spacecraft and propulsion systems. When certain systems are placed on board primarily to be evaluated for later Apollo vehicles, he shall be responsible for their operation, monitoring and evaluation. He shall occupy the right hand couch during launch and reentry.

3.4.2.7.1.2.4 General Duties.- All crew members shall be cross-trained so as to be able to assume the tasks usually performed by fellow crew members. Each shall stand watches during non-critical mission phases and perform all command and systems monitoring functions during such watches. While the commander shall be the principal navigator, the taking of navigational fixes and performance of associated calculations may be divided equally amongst all crew members.

3.4.2.7.2 Crew Integration.-

3.4.2.7.2.1 Displays and Controls.-

3.4.2.7.2.1.1 Arrangement.- Arrangement of displays and controls shall reflect the division of crew tasks. Critical piloting displays and controls shall be duplicated at the adjacent command and co-pilot stations. Non-duplicated piloting displays and controls shall be readily visible and accessible to both commander and co-pilot. All controls shall be of the self-locking type, or guarded to prevent inadvertent actuation. Instrument mountings shall ensure legibility of necessary displays during periods of vibration.

3.4.2.7.2.1.2 Manual Controls.- Manual control inputs to the Spacecraft attitude control system shall be provided at the left hand and center seats.

3.4.2.7.2.1.3 External View Devices.- Windows and other external viewing devices shall be provided to permit maximum feasible use of direct vision during rendezvous, earth landing, scientific observations and monitoring of crewmen operating outside the Spacecraft.

3.4.2.7.2.1.4 Operation by Single Crew Member.- Controls and displays shall be so arranged as to permit one crew member to return the vehicle safely to earth. However, this requirement shall not cause systems designs which result in degraded reliability for three man operation.

3.4.2.7.2.2 Crewspace Arrangement.-

3.4.2.7.2.2.1 Primary Duty Stations.- The primary displays, controls, and support systems shall be so arranged that the crew members are generally side-by-side during launch, entry, and similar critical mission phases. During other mission phases at least one couch shall be completely removed or stowed in order to provide additional work space and access to other work areas within the Command Module.

3.4.2.7.2.2.2 Secondary Duty Stations.- Areas for taking navigation fixes, performing maintenance, food preparation, and certain scientific observations may be separate from the primary duty stations.

3.4.2.7.2.2.3 Watch Station.- One of the primary duty stations shall be the station at which one crew member stands watch during non-critical mission phases. Some immediate control over all critical systems must be accessible at that station.

3.4.2.7.2.2.4 Sleeping.- There shall be a specific area assigned for sleeping. It shall accomodate a single crewman. It shall be placed in such a manner as to permit control of noise, light, and other distractions.

3.4.2.7.2.2.5 Toilet.- There shall be a specific area assigned to a toilet for collection of human waste. It shall accomodate a single crewman. It shall be so placed as to permit temporary partitioning for privacy.

3.4.2.7.2.2.6 Radiation Shielding.- The mass of the Spacecraft modules shall provide the majority of the bulk shielding. Arrangement of this mass shall be optimized to provide maximum shielding protection, both by its arrangement and by the position of the crew members without unduly compromising the system.

3.4.2.7.3 Crew Equipment.-

3.4.2.7.3.1 Acceleration Protection.-

3.4.2.7.3.1.1 Design Approach.- Design of the crew support and restraint systems shall be integrated with the design of the Earth-Landing and Launch Escape Propulsion Systems.

3.4.2.7.3.1.2 Couch.- Each crewman shall be provided with a support couch for protection against acceleration loads. The couch shall provide full body and head support during all nominal and emergency acceleration conditions. During launch and entry, the couch shall support the crew members at body angles specified in figure 74. The couch shall be adjustable to permit changes in body and leg angles to improve comfort during non-acceleration mission phases. Couches shall be so constructed as to permit crewmen to interchange positions. To meet the interchange requirements, sizing may be accomplished by use of simple couch adjustment devices. Couch construction and materials shall not amplify any accelerating forces by a factor of more than 1.2. The couch shall accomodate a crewman wearing a back type or seat type personal parachute. The parachute shall remain in the couch when the crewman leaves his restraint system. The couch shall accomodate crewmen in both pressurized and unpressurized pressure suits when used. The couch shall permit ease in ingress and egress during all nominal and emergency mission conditions. All couches shall be easily removable for the purpose of preflight and inflight maintenance.

3.4.2.7.3.1.3 Restraint System.- A Restraint System shall be provided with each couch. The system shall allow the interchange of crewman with simple attachment and adjustment for comfort and sizing. The torso portion of the Restraint System shall also serve as a personal parachute harness. The Restraint System shall provide adequate restraint for all nominal and emergency flight phases; landing loads and high dynamic pressure aborts are particularly significant in design of the Restraint System.

3.4.2.7.3.1.4 Impact Attentuation.- Impact attenuation beyond that required to maintain general Spacecraft integrity shall be obtained through use of discrete shock mitigation devices for individual crew support and restraint systems. Attenuation devices shall provide for lateral as well as transverse acceleration loads.

3.4.2.7.3.1.5 Vibration Attenuation.- Vibration attenuation beyond that required to maintain general Spacecraft integrity shall be provided with each support and restraint system. Such vibration attenuation systems must keep vibration loads transmitted to the crew within tolerance limits and also permit the crew to exercise necessary control and monitoring functions.

3.4.2.7.3.1.6 Restraint for Weightlessness.- An appropriate method of restraint shall be provided for a sleeping crew member.

3.4.2.7.3.2 Decompression Protection.- Pressure suits shall be provided for extra vehicular operations and in the event of cabin decompression. The same pressure suits shall be utilized for extra vehicular operations and cabin decompression emergencies. Mission reliability and crew safety requirements shall be satisfied without the use of pressure suits for cabin decompression. No beneficial effect on calculated reliability or crew safety shall be included in the analysis; nor shall there be any unrealistic compromise of Spacecraft systems imposed wholly by the use of pressure suits.

3.4.2.7.3.3 Sanitation.-

3.4.2.7.3.3.1 Human Waste.- The Spacecraft shall have a toilet for collection of urine and fecal waste. The toilet shall accomodate a single crewman. The toilet shall be placed in such a manner to permit use of temporary curtains or partitions for privacy. The collection system shall include means for disinfecting human waste sufficiently to render it harmless and unobjectional to the crew. All human waste shall be stored aboard the Spacecraft.

3.4.2.7.3.3.2 Personal Hygiene.- The Spacecraft shall be equipped with facilities for shaving, dental cleansing, bodily cleansing, and deodorizing. Facilities shall be included for cleansing of garments or for an appropriate number of garment changes.

3.4.2.7.3.3.3 Non-Human Waste.- The Spacecraft shall have provisions for handling of all other waste such as those from eating and personal hygiene.

3.4.2.7.3.3.4 Control of Infectious Germs.- The Spacecraft systems operation shall provide means for controlling infectious organisms which would have an unfavorable effect upon the crew members.

3.4.2.7.3.4 Food and Water.-

3.4.2.7.3.4.1 Food.- All food shall be of the dehydrated, freeze-dried or similar type that is reconstituted with water or does not require reconstitution. The food shall have a variety of flavor and texture similar to that provided in normal earth diets. There is no requirement for refrigerated storage; however, the foods shall require heating and chilling in preparation and service. The food items shall constitute a low bulk diet.

3.4.2.7.3.4.2 Water.- The primary source of potable water is from the fuel cell. In addition, sufficient water must be on board at launch to provide for the 72 hour landing requirement in event of early abort. Urine need not be recycled for potable water.

3.4.2.7.3.5 Emergency Equipment. -

3.4.2.7.3.5.1 Survival Equipment.- Post-landing survival equipment shall include one three-man life raft, food, location aids, first aid equipment and various accessories necessary to support the crew outside the Spacecraft for three days in any possible emergency landing area. Provisions shall be included for removing a three day water supply from the Spacecraft after landing; in addition, provisions shall be included for purifying a three day supply of sea water in event of water landing.

3.4.2.7.3.5.2 Personal Parachutes.- Each crewman shall be equipped with a personal parachute for use in event that the Spacecraft landing system malfunctions, cannot function, or cannot cope with local hazards. The personal parachute shall be stowed in the back or seat of each couch; the restraint harness shall serve as the parachute harness.

3.4.2.7.3.5.3 First Aid Equipment.- The Spacecraft shall be equipped with first aid and preventive medicine items for coping with various human injuries and disorders. If feasible, Spacecraft first aid equipment may be integrated with survival equipment first aid items.

3.4.2.7.3.6 Radiation Dosimeters.- Each crew member shall be provided with an accurate, simply read, personal dosimeter system. The dosimeter system shall be worn or placed immediately adjacent to the crew members at all times. Each system shall measure cumulative dose, shall contain a warning device, and shall have an output plug for telementry signals.

3.4.2.7.3.7 Medical Instrumentation.-

3.4.2.7.3.7.1 Physiological Measurements.- Ultimate monitoring and telemetry requirements will be specified by NASA on the basis of early studies and operations. At this time it appears that the crew will perform all physiological monitoring of each other, except as noted below. Measurements shall be taken with simple, clinical devices; significant findings shall be reported by voice. One physiological parameter may be sensed automatically and telemetered periodically.

3.4.2.7.3.7.2 Early Orbital Missions. - During early Apollo orbital flights, a variety of biological instrumentation will be required to enhance crew safety and assess the crew's tolerance to long term weightlessness. During stressful periods of such early flights, the following data may be telemetered:

Electrocardiogram	2 channels
Blood pressure	Intermittently: shares ECG channels
Respiration rate and volume	1 channel
Body temperature	Commutated

During non-stress mission phases the above may be recorded intermittently on a programmed basis. Electroencephalography may also be required during non-stress phases. In addition to the above, various special physiological experiments will be performed in the Spacecraft as part of the NASA-furnished scientific payload.

3.4.2.7.3.7.3 Extra-Vehicular Operations. - During lunar exploration or manned extra-vehicular pressure suit operations, the following data shall be transmitted from the extra-vehicular suit and monitored within the Command Module or Lunar Excursion Module: voice, one physiological function (respiration, heartbeat, or electroencephalogram), and one to four environmental parameters (pressure, temperature, carbon dioxide, oxygen). The Spacecraft displays shall permit switching between and identification of simultaneously operating extra-vehicular suits.

3.4.2.7.3.8 Other Crew Equipment. -

3.4.2.7.3.8.1 Garments. - In addition to pressure suits, the crew shall be provided with garments for wear during normal mission phases. These garments shall be comfortable, close fitting, and free of areas that would snag on Spacecraft equipment. The garment must be wearable under the pressure suit. Each crewman shall be provided with a light-weight cap to protect his head and eyes from injury as a result of collision with Spacecraft equipment. This cap may be separate from the pressure suit helmet.

3.4.2.7.3.8.2 Exercise.- Equipment shall be provided to permit the crew to exercise and maintain physical condition while in a weightless state.

3.4.2.7.3.8.3 Recreation.- The crew shall be provided with items for amusement and entertainment during off-duty periods.

3.4.2.8 Environmental Control System.- The Command and Service Modules shall include the Environmental Control System which provides a conditioned, "shirtsleeve" atmosphere for the crew; provisions for pressure suits in event of cabin decompression; thermal control of all Command and Service Module equipment where needed; and provisions for charging self-contained extra-vehicular pressure suit support systems ("back packs").

3.4.2.8.1 Requirements.- The system shall satisfy the following:

3.4.2.8.1.1 Metabolic.- The following conditions shall be provided by the Environmental Control System.

Total cabin pressure (O_2 and N_2 mixture) 7 ± 0.2 psia

Relative humidity 40 - 70%

Partial Pressure CO_2 - maximum 7.6 mm Hg

Temperature $75^{\circ} \pm 5^{\circ}$ F

3.4.2.8.1.2 Pressure Suit Operation.- The system shall provide for the use of individual pressure suits. In event of cabin decompression, the system shall provide a conditioned oxygen atmosphere at 3.5 psia to the suits. The system must be capable of maintaining a cabin oxygen partial pressure of at least 3.5 psia for 5 minutes following a single one-half-inch diameter puncture in the pressure compartment in addition to the normal structural design criteria.

3.4.2.8.1.3 Equipment Cooling.- The system shall provide thermal control for equipment. No critical equipment shall depend upon the cabin atmosphere for cooling or depressurization.

3.4.2.8.2 System Description.- Environmental control is accomplished with two air loops, a gas supply system and a thermal control system. (See Fig.75.)

3.4.2.8.2.1 Air Loops.-

3.4.2.8.2.1.1. Regenerative Circuit Loop.- This loop supplies the conditioned atmosphere to the cabin and/or pressure suits.

3.4.2.8.2.1.1.1 Particulate Removal.- A debris trap shall be provided.

3.4.2.8.2.1.1.2 Noxious Gases.- Noxious gases shall be removed by activated charcoal and a catalytic burner with the latter provided with a regenerative heat exchanger. A gas analyzer shall be provided.

3.4.2.8.2.1.1.3 Carbon Dioxide.- Carbon dioxide shall be absorbed by lithium hydroxide. The system shall provide for two parallel isolated lithium hydroxide canisters. The size of canisters and method of cartridge replacement shall be optimized.

3.4.2.8.2.1.1.4 Atmospheric Circulation.- The loop shall be provided with three parallel isolated blowers, any one of which will circulate the required flow. One operating blower shall be capable of supplying the following requirements to all three pressure suits simultaneously: Ventilation flow at 3.5 psia shall be 12 CFM thru each suit; maximum flow resistance of each suit shall be 5" of water at 12 CFM, 3.5 psia. Each pressure suit connection shall have a bypass which will permit individual manual flow control.

3.4.2.8.2.1.1.5 Temperature Control.- A liquid coolant heat exchanger system shall be provided to cool the circulating air below the required dew point for condensate removal and humidity control. A regenerative heat exchanger shall be provided for the crew to control their inlet air temperature. A water evaporator shall also be provided for cooling of circulating air in event of loss of coolant.

3.4.2.8.2.1.1.6 Humidity Control.- The condensed water vapor shall be removed by either of two parallel isolated separators. Air-driven centrifugal water separators shall be developed for use. The development of a sponge type water separator shall be pursued until the desired use of the centrifugal separator is unquestioned.

3.4.2.8.2.1.2 Cabin Loop.- The loop serves to provide cabin ventilation and thermal control during all phases of the mission and postlanding ventilation.

3.4.2.8.2.1.2.1 Atmospheric Circulation.- The loop shall be provided with two fans, either of which is capable of circulating the required flow and shall be designed to operate as an efficient exhaust fan during the post-landing phase. Snorkels shall be provided for post-landing.

3.4.2.8.2.1.2.1 Temperature Control.- A liquid coolant heat exchanger shall be provided to control cabin air temperature. It shall be designed to minimize fan power during the post-landing phase.

3.4.2.8.2.2 Gas Supply System.- The primary gas supplies shall be stored as super critical cryogenics in the Service Module. Storage of these supplies is discussed in connection with the Electrical Power System.

3.4.2.8.2.2.1 Primary Gas Requirements.- The gas supply shall have a 50 percent excess capacity over that required for normal metabolic and leakage needs, plus two complete cabin repressurizations, and a minimum of 18 air lock operations.

Provisions shall be made for recharging portable life support systems ("back packs").

3.4.2.8.2.2.2 Reentry Oxygen.- The Command Module shall contain a supply of gaseous oxygen in a high pressure bottle which shall be sufficient for reentry. A completely redundant system shall also be provided.

3.4.2.8.2.3 Thermal Control.- The normal dissipation of the internal thermal load of the Spacecraft is accomplished by absorbing heat with a circulating coolant and rejecting this heat from a space radiator during certain mission modes. Other cooling systems will supplement or relieve the primary system.

3.4.2.8.2.3.1 Radiator.- The space radiator shall be integral with the skin on the Service Module. For redundancy, dual coolant loops using radiator panels shall be provided. The radiator shall be designed to adequately meet the deep space random orientation condition. In addition, the radiator design shall be compatible with the water management program.

3.4.2.8.2.3.2 Coolant Loop.- The liquid coolant rejection transport fluid shall circulate through the regenerative circuit loop heat exchanger, electrical equipment cold plates, water evaporater gas storage heat exchanger, and the space radiator. Alternate liquid coolant passages in the equipment cold plates shall be provided. The liquid coolant flow shall be provided. The liquid coolant flow shall be maintained at fixed rate by one of three hermetically sealed, constant speed pumps. The redundant reservoir accumulator shall allow for a complete recharging of the liquid coolant. Provisions shall be made for a gas check before recharging in the event of a rupture to allow for isolation of leakage zones and to reestablish system integrity.

3.4.2.8.2.3.3 Mission Modes.-

3.4.2.8.2.3.3.1 Prelaunch (PAD).- Before lift-off the space radiator shall be isolated and the total heat load dissipated by cooling the liquid coolant in the water evaporator with ground support freon.

3.4.2.8.2.3.3.2 Launch.- After lift-off and attainment of sufficient altitude, water will be substituted in the evaporator for cooling.

3.4.2.8.2.3.3.3 Orbit.- The water evaporated in the liquid coolant loop may be used to supplement the radiator in earth and lunar orbit.

3.4.2.8.2.3.3.4 Transit.- The radiator shall be capable of dissipating the total heat load in spacecraft orientation during transit.

3.4.2.8.2.3.3.5 Reentry.- During reentry the thermal load shall be cooled by water evaporation in the liquid coolant heat exchanger. In event of liquid coolant loss, the metabolic heat load shall be cooled by a water evaporator in the regenerative suit-circuit loop.

3.4.2.8.2.3.3.6 Extra-Vehicular Pressure Suit Operations.- The Environmental Control System shall not directly support pressure suits during extra-vehicular operations. During such operations, the suits shall be supported by portable life support systems ("back packs").

3.4.2.8.2.4 Controls.- Control of atmospheric pressures, humidity and temperature shall be automatic with provisions for manual surveillance and control.

3.4.2.8.3 Water Management.- Water shall be collected from the separator and the fuel cell and stored in positive expulsion tanks. The water collected from the fuel cells shall be stored separately and used as the primary source of potable water.

3.4.2.8.3.1 Water Requirements.- Water shall be provided at lift-off to satisfy the crews postlanding metabolic needs and provide for evaporative cooling during exit and reentry following an immediate abort. A water management program shall be encompassed in the design to provide water requirements for all other phases of the mission.

3.4.2.8.4 Safety Features.- All relief valves, snorkel valves, and other valves which connect the internal pressure vessel to the space environment shall have manual closures and/or overrides. Filters shall be provided to protect all regulators, control valves, gas analyzers, etc. Relief valves shall be provided to prevent overpressurization of low pressure components. Flow limiting devices shall be provided to prevent excessive use of gas supplies and subsequent depletion of such supplies.

3.4.2.8.5 Preflight Checkout.- Fittings with proper access shall be provided to perform pressure checks, component performance tests, etc. during preflight checkout. This requirement is to preclude the necessity of breaking system integrity for component tests. Provisions shall be made for testing and calibrating all environmental sensors.

3.4.2.9 Electrical Power System.-

3.4.2.9.1 System Description.-

3.4.2.9.1.1 Purpose.- The Electrical Power System shall supply, regulate, and distribute all electrical power required by the Command and Service Module for the full duration of the mission, including the post-landing recovery period.

3.4.2.9.1.2 Major Components.- The Electrical Power System shall be comprised of the following major components.

a. Three (3) non-regenerative hydrogen-oxygen fuel-cell modules.

b. Mechanical accessories, including control components, reactant tankage, piping, radiators, condensors, hydrogen circulators and water extractors, isolation valves and such other devices as required.

c. Three (3) silver-zinc primary batteries, each having a nominal 28 volt output and a minimum capacity of 3000 watt-hours (per battery) when discharged at the 10 hour rate at 80°F.

d. An Electrical Power System display and control panel, sufficient to monitor the operation and status of the system and for distribution of generated power to electrical loads, as required.

3.4.2.9.1.3 Location and Weight.- The location of each of the above components within the spacecraft shall be as listed herein. Every effort shall be exercised to minimize equipment size and weight, commensurate with the established requirements and obtaining the highest practicable reliability.

Component	Location
Fuel-cell module and controls	Service Module
Tanks (empty), Radiators, Heat exchangers, Piping, Valves	Service Module
Total Reactants, plus reserves	Service Module
Silver-Zinc Batteries	Command Module
Electrical power distribution and controls	Command Module

3.4.2.9.1.4 Operating Modes.-

3.4.2.9.1.4.1 Normal Operation.- During all mission phases, from launch until reentry, the entire electrical power requirements of the Command and Service Module shall be supplied by the three fuel-cell modules operating in parallel. The primary storage batteries would be maintained fully charged under this condition of operation.

3.4.2.9.1.4.2 Emergency Operation.- In the event of failure to one of the fuel-cell modules the failed unit would be electrically and mechanically isolated from the system and the entire electrical load assumed by the two fuel-cell modules remaining in operation. The primary batteries would be maintained fully charged under this condition of operation.

In the event of failure of two of the fuel-cell modules, the failed units would be electrically and mechanically isolated from the system. Spacecraft electrical loads would be immediately reduced by the crew and manually programmed to hold within the generating capabilities of the remaining operable Fuel-Cell Module. The primary batteries would be recharged,if necessary, and maintained fully charged under this operating condition.

3.4.2.9.1.4.3 Reentry and Recovery.- At reentry, the Fuel-Cell Modules and accessories will be jettisoned. All subsequent electrical power requirements shall be provided by the primary storage batteries.

3.4.2.9.2 System Requirements.-

3.4.2.9.2.1 Fuel-Cell Module.- Each Fuel-Cell Module shall have the following performance characteristics.

3.4.2.9.2.1.1 Type.- Fuel-Cell Modules shall be of the low pressure intermediate temperature, Bacon-type, utilizing porous nickel, unactivated electrodes and aqueous potassium hydroxide as the electrolyte. Fuel cells shall be operated non-regeneratively, utilizing hydrogen and oxygen as the reactants.

3.4.2.9.2.1.2 Output Power.- Each Fuel-Cell Module shall have a nominal capacity of 1200 watts at an output voltage of 28 volts and a current density conservatively assigned such that 50% overloads can be continuously supplied.

3.4.2.9.2.1.3 Pressure and Temperature.- The nominal cell operating pressure and temperature shall be approximately 60 psia and 425°F to 500°F respectively.

3.4.2.9.2.1.4 Fuel Consumption.- Under normal conditions of operation, the specific fuel consumption shall not exceed 0.9 lb/Kw-Hr, total H_2 and O_2.

3.4.2.9.2.1.5 Water Generation.- The water generated by the Fuel-Cell Module shall be potable and shall be separated from the hydrogen and stored.

3.4.2.9.2.1.6 Start Up.- Self-sustaining reaction within the Fuel-Cell Module shall be initiated at a temperature of approximately 275°F. Integral heaters shall be provided to facilitate ground starting as well as during the mission. These heaters shall not be capable of heating units to excessive temperatures with the fuel-cell and its cooling system inoperative.

3.4.2.9.2.1.7 Fuel-Cell Modules.- A detection and control system shall be provided with each Fuel-Cell Module to prevent contamination of the collected water supply.

3.4.2.9.2.1.8 System Redundancy.- The degree of redundancy provided for mechanical and electrical accessory equipment such as radiator loops, control valves, piping circuits, voltage regulator, etc., shall, in general, be 100 percent.

3.4.2.9.2.2 Electrical Distribution.-

3.4.2.9.2.2.1 General.- The distribution portion of the electrical power system shall contain all necessary busses, wiring protective devices, switching and regulating equipment.

Except as specified herein, the electrical distribution system shall conform to the requirements of standard MIL-STD-704.

Selection of parts and materials, workmanship, fabrication and manufacturing processes shall be guided by the requirements of MIL-E-5400, except as required to meet the performance or design requirement specified herein.

3.4.2.9.2.2.2 System Voltage.- Electrical power shall be generated and distributed at 28 volts DC (nominal).

3.4.2.9.2.2.3 Regulation.- The voltage level shall be regulated to prevent variance of more than ±2 volts from the nominal voltage under all conditions of operation of the fuel cell system.

3.4.2.9.2.2.4 AC Ripple.- All DC busses in the system shall be maintained essentially free of AC ripple (as defined by paragraph 3.12 of MIL-STD-704) to within a limit of 250 millivolts peak to peak.

3.4.2.9.2.2.5 Protection.- Busses and electrical loads shall be selectively protected such that individual load faults will not cause an interruption of power on the bus to which the load is connected. Likewise, a fault on the nonessential bus shall not cause an interruption of power to the essential bus.

3.4.2.9.2.2.6 Load Grouping.- All electrical loads supplied by the distribution system shall be classified as Essential, Nonessential, Pyrotechnic, or Recovery. Essential loads are defined as those loads (except pyrotechnic circuits) which are mandatory for safe return of the spacecraft to earth from any point in the lunar mission. Such loads as are not mandatory for safe return of the spacecraft shall be grouped on the Nonessential bus and provision made for disconnecting these loads as a group under emergency conditions. All loads required during the post-landing recovery period shall be supplied by the Recovery bus and provision made for manually disconnecting this bus from the Essential bus following landing. Redundant busses shall be provided for pyrotechnic circuits, and used to supply only that type load.

3.4.2.9.2.2.7 Power Conversion.- Equipment which requires conversion of basic electrical power (28 volts DC) to power with other characteristics shall accept the basic power as defined herein for modification and use. Conversion or inversion devices required for this purpose shall be integral with the utilization system or utilization equipment, whenever practical.

3.4.2.9.2.2.8 External Power.- Provision shall be made to energize the distribution system from an external source (28 volts, 100 amps DC) through an umbilical connector and a blocking diode.

3.4.2.9.2.2.9 Electrical Distribution Panel.- The Distribution Panel shall be dead front and adequately enclosed or otherwise protected to minimize hazards to the crew and provide maximum mechanical protection for the electrical system and components. Switching and control shall be accomplished by manually operated circuit breakers or contactors in preference to electrically operated contactors, except where use of a remotely controlled device is necessary to reduce the length of large electrical conductors.

3.4.2.9.2.2.10 System Type.- The distribution system shall be a two-wire grounded system, i.e., wire and busses shall be employed as the return path for electrical currents, in lieu of using the spacecraft structure for this purpose. The system negative shall be grounded at one point only and shall not be interrupted by any control or switching device.

3.4.2.9.2.3 Reactant Tankage.-

3.4.2.9.2.3.1 General Requirements.- Sufficient tankage shall be provided to store all reactants required by the Fuel-Cell Modules and environmental controls for a 14-day mission. Reactants shall be stored supercritically at cryogenic temperatures and the tankage shall consist of two equal volume storage vessels for each reactant. The main oxygen and nitrogen storage shall supply both the Environmental Controls System and the fuel-cells.

3.4.2.9.2.3.2 Reserves.- The tankage volume shall include the fuel-cell fluid requirements plus 10% reserve and the environmental fluid requirements. The hydrogen storage volume shall include the fuel-cell requirements plus 10% reserve.

3.4.2.9.2.3.3 System Arrangement.- Adequate valves and controls shall be provided to isolate identical reactant tanks from each other, and from the environmental controls and

Fuel-Cell Modules. Valve arrangement shall allow flow from any reactant tank to any Fuel-Cell Module.

The schematic arrangement Figure 76 is intended only to convey to the vendor the requirements covered above, rather than the complete system arrangement.

[redacted]

3.4.2.10 Communication and Instrumentation System.-

3.4.2.10.1 General Design Requirements.- Equipment shall be constructed to facilitate maintenance by ground personnel and by the crew. Each system, together with the interconnecting cables, shall be as nearly self-contained as possible to simplify removal from the Spacecraft. The equipment and system shall be capable of sustained undergraded operation with supply voltage variation of +15 percent to -20 percent of the nominal bus voltage. Flexibility for incorporation of future additions or modifications shall be stressed throughout the design and assembly of all components and systems. Toward this end, the following features shall be provided:

a. Spare conductors shall be included in each wire group to permit system revisions or additions without necessitating retrunking of wire runs or additional bulkhead penetrations.

b. Insofar as possible, all spare contacts or relays, switches, contactors, etc., shall be wired and brought to an accessible point for future use, if needed.

A patch and programing panel shall be provided which will permit the routing of signal inputs from sensors to any selected signal conditioner and from these to any desired commutator channel. Panel design shall provide the capability of "repatching" during a mission.

3.4.2.10.1.2 Circuit Quality Analysis Chart.- The Contractor shall provide a circuit quality analysis for each radiating electrical system. The Contractor shall provide information showing exactly how ranging, telemetry, voice, and television data modulate all transmitters with which they are used. This information shall include:

a. Description of modulation systems used.

b. Bit rates used in each data mode.

c. Bandwidth required on subcarrier oscillators and main carrier.

d. Frequencies of all subcarrier oscillators and type of data on each.

[redacted]

3.4.2.10.2 Test and Maintenance.- The equipment and associated documentation shall be engineered for comprehensive and logical fault tracing. It shall be possible to check the operability of all functions of the equipment after installation in the Spacecraft. Each subsystem shall contain sufficient monitor points which are readily accessible to allow rapid and complete systems check. The equipment and systems shall be designed to facilitate prelaunch tests, before and after mating with the launch vehicle. Insofar as possible, the design shall provide for power control and system activation such that the maximum number of individual systems tests can be performed without full support or coordination with other spacecraft systems or those of the launch vehicle. It is of prime importance that the coupling of test equipment does not affect the on-board systems so that unrealistic test conditions are created. The uncoupling of system connections and the introduction of test cabling shall be kept to a minimum. Consideration shall be given to flexible automatic checkout equipment.

3.4.2.10.3 Communication System. - The Command and Service Module Communications System shall provide the following:

Voice Communication
Telemetry
Television
Tracking Transponders
Radio Recovery Aids
Antenna Subsystems
Radar Altimeter (if required by Guidance System)

The following systems descriptions are based upon GOSS utilization employing the currently supported HF, VHF, and C-band frequencies for near-earth communications, and the UHF frequencies for lunar distance communications. However, a transition to a single (unified) UHF carrier frequency, using modulation techniques typical of the present DSIF system is contemplated for both near-earth and lunar communications. The system design shall allow provision for this transition.

3.4.2.10.3.1 Voice Communication.- Two-way voice communication capability between the individual crew members, between the Spacecraft and earth-based stations, and between

[redacted]

each module in a rendezvous maneuver shall be provided. A personal communication system (NASA-supplied) shall provide two-way voice communication between crew members whether internal or external to the Spacecraft. An intercommunication (plug-in) system shall be supplied by the Contractor. Reliable communication in the near-earth phase of flight shall be afforded by a UHF link to that range at which DSIF communications can be acquired and maintained for all potential flight paths. Voice communication using the UHF DSIF transponder shall provide reliable voice transmission and reception to lunar distance.

3.4.2.10.3.2 Telemetry.- A flexible pulse-code-modulation telemetry subsystem compatible with both the VHF and UHF transmission systems shall be provided. Initial telemetry and display system design shall incorporate flexibility to add a ground spacecraft data link.

3.4.2.10.3.3 Television.- A television closed-circuit subsystem for use by the crew in monitoring internal and external scenes in real-time shall be provided. A portable television subsystem capable of real-time and high resolution picture transmission shall be provided. Optimum modulation method shall be employed. Frame rate and resolution trade-offs with transmitter power and antenna size shall be optimized.

3.4.2.10.3.4 Tracking Transponders.- A C-band transponder subsystem compatible with the AN/FPS-16 and equivalent radars shall be provided. This subsystem shall be capable of providing reliable tracking signals in the near-earth-phase of flight to that range at which DSIF tracking can be acquired and maintained for all potential flight paths. A UHF transponder providing reliable velocity and range tracking to lunar distance when used with the DSIF shall be supplied.

3.4.2.10.3.5 Radio Recovery Aids.- The radio recovery aids subsystem shall consist of an HF transceiver system which may be either voice or tone-modulated, and a VHF beacon.

3.4.2.10.3.6 Antennas.- The near-earth antenna system shall consist of multiple flush-mouthed antennas which essentially provide omnidirectional patterns in a plane perpendicular to the booster longitudinal axis. A similar antenna compatible with DSIF shall be used at minor deep-space distances. This antenna shall offer

[redacted]

sufficient gain for reliable transfer of priority information at a reduced banwidth in an emergency condition up to lunar distances. The directional antenna system shall be either designed for stresses encountered throughout the mission or be retractable for periods of high stress. Both manual and automatic antenna steering shall be provided for the directional antenna.

3.4.2.10.3.7 Radar Altimeter.- A rendezvous and altimeter radar system commensurate with guidance requirements shall be provided by the Contractor if such a system is required.

3.4.2.10.4 Instrumentation.-

3.4.2.10.4.1. General.- The Instrumentation System shall detect, measure and display all parameters required by the crew for monitoring and evaluating the integrity and environment of the spacecraft and performance of the Spacecraft systems. It shall provide data for transmission to earth, to facilitate ground assessment of Spacecraft performance and failure analysis. It shall provide the crew with information as required for abort decision. In addition, the capability shall be provided for documenting the mission through photography and recording.

3.4.2.10.4.2 Measurements.- A tabulation of measurements shall be provided and include the number and type of all measurements; sensor characteristics; conditions when taken (flight, flight phase, etc.); data disposition, i.e., displayed, real-time telemetry, recorded for telemetry playback, recorded for storage, etc. A block diagram showing the interrelationship of the instrumentation components shall also be provided.

3.4.10.4.3 Sensors.- The sensors selected for each application shall have an inherent reliability at least one order of magnitude greater than the measured and measuring subsystem and shall be compensated such that their capability to perform the intended function is not degraded by the environmental conditions to which they are subjected. Excitation voltage, where required, shall be standardized. Transducer output shall also be standardized, insofar as practicable. Inaccessible measurement areas shall be provided with both primary and spare sensors and associated auxiliary equipment as required. Electrical leads associated with the sensors shall be electrically shielded and mechanically secured so as to minimize the generation or pickup of noise by the leads.

3.4.2.10.4.4 Data Disposition.- The capability shall be provided for data transmission upon crew command or onboard programmed command (e.g., five minutes transmission each hour during the coast phase of the mission). Provisions shall be made for transmitting data in the following critical areas:

a. Measurements relating directly to conditions having an immediate effect on crew safety.

b. Sufficient measurements in each functional area or system to facilitate failure analysis in event of an unsuccessful flight.

c. Navigation and guidance data as required to permit ground station checking of vehicle position and course.

3.4.2.10.4.5 Tape Recorders.- One recorder system shall be provided for the storage of telemetry, voice, and possibly video information for later playback at the discretion of the crew, or for data storage pending spacecraft recovery. A second recorder system shall be provided for multichannel recording of high-frequency parameters such as sound and vibration. This recorder shall also be suitable for use in conjunction with the scientific and biomedical instruments.

3.4.2.10.4.6 Panel Display Indicators.- The panel display indicator shall not be coupled directly to those data channels which are providing similar information to the telemetry or recording system, i.e., there shall be no coupling between the panel display instruments and telemetry/ recording channels which could result in cross effects between the circuits, even in event of malfunction.

3.4.2.10.4.7 Calibration.- A calibration feature shall be provided as an integral part of the measurement system and shall be such as to provide a rapid analytic assessment of the measurement system's performance. The method of calibration shall encompass the overall system where practicable, and in addition shall include selectivity of automatic or manual operation at the crew's discretion.

3.4.2.10.4.8 Clock.- Redundant, real-time, binary code generating devices shall be provided to act as the primary time reference; to correlate all data; and to function as an integral part of all time-critical operations. The accuracy and stability of the clock under the environmental conditions expected shall be compatible with the navigation and guidance requirements and future scientific needs.

3.4.2.10.4.9 Telescope.- A gimbal-mounted telescope shall be provided to aid in visual study and photography of the lunar surface and celestial bodies. Dual operating modes shall be possible (high power - narrow angle field of view, or low power - wide angle field of view). Reference axis information shall be provided.

3.4.2.10.4.10 Cameras.- Two onboard time correlated cameras shall be used on board; one suitable for monitoring the crew, displays, and spacecraft interior; the other suitable for lunar photography and stellar studies. The latter camera shall be capable of use in conjunction with the telescope or independent use at the crew's discretion.

3.4.3 Lunar Excursion Module Systems.- The characteristics of the major systems included in the Lunar Excursion Module are presented.

3.4.3.1 Guidance and Control System.- The concept of a Lunar Excursion Module landing and returning for a lunar orbit rendezvous imposes the following requirements on the control and guidance system of the Lunar Excursion Module.

a. Control of de-orbit impulse to follow planned trajectories.

b. Braking hovering and translational control to select the most desirable landing point.

c. Lunar launch guidance to rendezvous with the parent vehicle.

d. Docking with the parent vehicle.

e. Providing abort guidance and control during all phases.

3.4.3.1.1 The Guidance and Control System is essentially divided into two systems. The Navigation and Guidance System will be furnished by MIT. The Stabilization and Control System is the responsibility of the LEM Contractor.

3.4.3.1.2 Guidance System.- The Guidance System is similar to the guidance system in the Apollo command module thus insuring that the Spacecraft in lunar orbit and/or the Lunar Excursion Module can direct the maneuvers for lunar rendezvous. Since the Lunar Excursion Module has no requirement for atmospheric reentry guidance there is some simplication and modification of the system.

3.4.3.1.3 Stabilization and Control System.- This system on the Lunar Excursion Module shall provide the logic and information for attitude control during free Lunar Excursion Module flight, thrusting, hovering, vernier corrections for docking, lunar landing and lunar orbit rendezvous maneuvers. Consideration shall be given to the provision of a backup guidance scheme utilizing elements of the Stabilization and Control System where possible.

3.4.3.2 Lunar Excursion Propulsion System:

3.4.3.2.1 General Description.- The Lunar Excursion Propulsion System will be located in the Lunar Excursion Module and will provide propulsion requirements for the Lunar Excursion Module for lunar landing, lunar launch and lunar orbit rendezvous with the Command and Service Module. The Lunar Excursion Propulsion System will utilize earth-storable hyperbolic propellants and will have a pressurized propellant feed system. Variable thrust is required.

3.4.3.2.2 Performance Requirements- The Lunar Excursion Propulsion System will be required to provide propulsion requirements for the Lunar Excursion Propulsion Module as follows.

3.4.3.2.2.1 Lunar Orbit Transfer.- The velocity increment required to transfer from a circular to an elliptical lunar orbit.

3.4.3.2.2.2 Lunar Landing.- The velocity increment required to land the Lunar Excursion Module on the lunar surface including translation and hovering requirements.

3.4.3.2.2.3 Lunar Launch.- The velocity increment required to launch the Lunar Excursion Module from the lunar surface into an elliptical lunar orbit including the effects of the lunar gravitational field.

3.4.3.2.2.4 Lunar Orbit Transfer.- The velocity increment required to transfer from an elliptical orbit to the Command and Service Module circular orbit.

3.4.3.2.2.5 Lunar Rendezvous.- The major velocity increment required to rendezvous the Lunar Excursion Module with the Command and Service Module.

3.4.3.2.3 System Operation

3.4.3.2.3.1 Operating Features.- The propellant pressurization gas tank or tanks shall be sealed in a positive manner by redundant squib valves to prevent leakage prior to use. Redundancy in the pressure regulators shall be provided. A propellant utilization system to control proper oxidizer-fuel ratio shall be considered. Redundant propellant valves to guard against failure in the open or closed mode are required. Variable thrust capability is to be provided and a variable area injector or upstream variable orificing may be used. The injector shall be designed to operate with maximum tolerance to system contamination with no catastrophic failure of the thrust chamber. Single or multiple thrust chamber configurations shall be designed with consideration being given to provide the most reliable Lunar Excursion Module. A single, partially or two-staged propulsion system shall be designed to provide the most otimum lunar landing and lunar launch system. In designing the thrust chamber, consideration shall be given to designing for off normal conditions such as over pressure transients, injectors plugging, and streaking.

3.4.3.2.3.2 Safety Features.- Filters to protect critical components such as pressure regulators and injectors and at the discharge of squib valves are required. Check valves to prevent oxidizer-fuel cross flow shall be provided in the pressurization lines. Relief valves with burst disc in series and located on the relief valve inlet side shall be provided to protect the propellant tanks fcrm over pressure. Redundant actuation should be provided for the variable thrust orifice. Pressurization gas and propellant tanks shall be sealed by burst discs or squib valves and check valves. Maximum use of welded or brazed lines should be used to minimize leak points. Use of failure indicating circuits should be minimized.

3.4.3.2.3.3. Preflight Checkout.- Test points are to be provided to pressure check, purge and flow check all parts of the propulsion system. Provisions for checking all sensors and flight instrumentation shall be made. The system shall be capable of being static-fired as an entire system prior to flight. The variable thrust injector or orifice shall be designed to provide maximum thrust in event of failure in any lower thrust position.

3.4.3.2.4 Crew Participation.-

3.4.3.2.4.1 Monitoring Function.- The crew shall be able to monitor system pressures and temperatures, thrust chamber pressure, and propellant level. Engine variable thrust injector device position should also be indicated. If a propellant utilization system is provided, means of monitoring its operation shall be provided.

3.4.3.2.4.2 Normal Operation.- Arming the propulsion system for operation shall be a crew function. Actual system initiation shall be an automatic function controlled by the guidance system. Variation in thrust level shall also be controlled by the guidance system. If a two staged or partially staged propulsion system configuration is used, initiation of separation shall be a crew function. The crew shall be able to monitor the automatic guidance functions.

3.4.3.2.4.3 Emergency Operation.- Automatic switchover to redundant system components such as pressure regulators or propellant valves shall be provided. Manual override of thrust by the crew is required. The crew shall be able to override any automatic function. Provisions for propulsion system inspection and maintenance by the crew while on the lunar surface shall be provided.

3.4.3.2.5 Guidance System Requirements

3.4.3.2.5.1 Thrust-Vector Control.- Thrust vector control may be provided by gimbaling the Lunar Excursion Propulsion Engine or by use of the Lunar Excursion Reaction Control System. If the Lunar Excursion Propulsion Engine is to be gimbaled, redundant gimbal actuation systems are to be provided.

3.4.3.2.5.2 Velocity Cut-Off Control.- Velocity cut-off control and repeatability shall be consistent with the requirements of the lunar landing and launch mission.

3.4.3.2.6 Propellants. The Lunar Excursion Propulsion System shall use an earth storable hyperbolic by propellant combination.

3.4.3.2.6.1 Oxidizer.- The oxidizer shall be nitrogen tetroxide (N_2O_4) with nitrous oxide (N_2O) added to depress the freezing point if necessary.

3.4.3.2.6.2. Fuel.- The fuel shall be monomethylhydrazine (MMH).

3.4.3.2.7 Performance.- The minimum three sigma deviation of specific impulse during engine operating life shall not be less than 305 $\frac{\text{lb/sec}}{\text{lb}}$.

3.4.3.3 Reaction Control System.- The Lunar Excursion Module Reaction Control System shall consist of two independent, interconnectable sub-systems, each capable of meeting the total torque and impulse requirements. Each sub-system shall provide two-directional control in all axes. The reaction control system shall utilize hypergolic bipropellants and shall be pulse-modulated.

3.4.3.3.1 Thrust Chambers.- The thrust chambers shall be radiation-cooled and performance shall be optimized for the application.

3.4.3.3.2 Propellant Tanks.- Each sub-system shall have one oxidizer and one fuel tank. Each tank shall be equipped with a bladder for zero gravity expulsion. Bladders shall be capable of multiple cycling.

3.4.3.3.3 Propellant Feed.- Normally the pair of propellant tanks in each sub-system shall feed all thrust chambers in that particular sub-system. However, reversible isolation valves shall be furnished to allow isolation of the thrust chambers in each axis. Reversible valves shall be furnished to allow propellant feed from the launch propulsion tankage. In these redundant modes of propellant feeds, quad check valves shall be utilized to prevent transfer of propellants from one sub-system to the other sub-system tankage or to the propulsion system.

3.4.3.3.4 Pressurization.- Each sub-system shall have a gaseous helium storage and pressurization system. Quad check valves shall be used at each propellant tank feed. redundant squib valves may be used to isolate the high pressure storage until the system operation is required. However, provisions shall be made for ground servicing and checkout.

3.4.3.3.5 Propellants.- The same propellant combination as used for the propulsion system shall be utilized in the reaction control system. The fuel shall be of the hydrazine family with nitrogen tetroxide or mixed oxides of nitrogen as the oxidizer. Final selection of the combination shall be made only after an analysis of performance and environmental factors.

3.4.3.4 Lunar Touchdown System.- The Lunar Excursion Module incorporates a Lunar Landing Touchdown System to arrest impact, support the Lunar Excursion Module during its period on the moon, and provide a launching base.

3.4.3.4.1 Structural Load Paths.- The Lunar Touchdown System shall be designed to take advantage of existing structural arrangements provided for tankage and general propulsion systems. Hard points are to be provided on the Lunar Excursion Module which will accommodate variations in landing gear geometries and have load distribution capabilities compatible with anticipated landing gear loads.

3.4.3.4.2 Interference with Other Systems.- The Lunar Touchdown System shall be designed such that in all positions of stowage and deployment it does not interfere with the use of the propulsion systems for lunar descent or attitude control purposes.

3.4.3.4.3 Stowability.- The Lunar Touchdown System is stowed in available free space of the adapter.

3.4.3.4.4 Deployment.- Deployment may be performed manually by crew in extra-vehicular suit.

3.4.3.4.5 Inspection,Maintenance and Servicing.- The design shall be such that advantage can be taken of the crew's capabilities in extra vehicular suits both in flight and on the lunar surface, for inspection, maintenance and servicing. Crew participation is to be considered where significant advantage is attained in reducing complexity and improving reliability without undue demands on the crew's capabilities.

3.4.3.4.6 Lunar Landing Aids.- The use of deploying landing aids from the Lunar Excursion Module, such as penetrometers, at near the hover altitude should be considered.

3.4.3.4.7 Post Landing Attitude.- The Spacecraft inherently shall return to or be in a near vertical condition satisfactory for lunar launch or normal egress.

3.4.3.4.8 Surface Condition.- The Lunar Touchdown System shall cater for landings on maria surfaces or crater floors as described in the lunar surface criteria of Reference 16.

3.4.3.5 Structural System.- In addition to the fundamental load carrying structures, the Lunar Excursion Module structural system shall include meteoroid protection radiation protection inherent in the structures and passive heat protection. Primary structures shall be designed and evaluated in accordance with standard aircraft practice and by the same criteria as are the Command and Service Module.

3.4.3.6 Crew System.- The flight crew, their responsibilities, integration and personal support equipment are described here.

3.4.3.6.1 Flight Crew.- The commander (pilot) and the pilot system manager from the command module comprise the Lunar Excursion Module flight crew and the second-in command pilot navigator remains with the command module. Each crew member performs the functions assigned in Section 3.4.2.7 with the additional requirements that they participate in the lunar surface operations and preparation of records.

3.4.3.6.2 Crew Integration.- The crew work space arrangement shall reflect the on-board command and control responsibilities of the crew and provide for active on-board management of the flight control system and spacecraft subsystems.

3.4.3.6.2.1 Displays and Controls.- The displays and controls shall provide maximum crew effectiveness and spacecraft reliability. Division of crew tasks shall be reflected in the displays and controls arrangement. Location of all displays and controls shall not require either crewman to be mobile during the lunar landing or launch phases of the mission.

3.4.3.6.2.2 Manual Control.- All manual controls which are subject to inadvertant actuation during crew ingress and egress shall be provided with locks or guards. Such safety devices shall not degrade the reliability of the control system or crew performance.

3.4.3.6.2.3 Operation by Single Crew Member.- Controls and displays shall be arranged to permit one crew member to return the Lunar Excursion Module safely to the Command Module. However, this requirement shall not cause degraded reliability or crew performance for two man operation.

3.4.3.6.3 Crew Support.- Each crew man shall be provided with a seat capable of supporting against acceleration loads. The seat shall be adjustable to provide for a comfortable rest position and for rendezvous and docking visibility.

3.4.3.6.4 Restraint System.- A restraint system shall be provided with each seat. It shall provide adequate restraint for all nominal and emergency flight phases. Lunar landing loads and liftoff accelerations are particularly significant in the design of this system.

3.4.3.6.5 Extra-Vehicular Suit.- The extra-vehicular suit for lunar exploration is to be developed under separate specifications.

3.4.3.6.6 Food.- The food items shall constitute a low bulk diet. The food shall be of the dehydrated, freeze-dried or similar type that is reconstituted with water or does not require reconstitution. There are no requirements for refrigeration. Advantage shall be taken of the lunar gravity influence on food and drink.

3.4.3.6.7 Water.- Water requirements for consumption and vehicle cooling shall be on-board at earth launch.

3.4.3.6.8 First Aid Equipment.- The Lunar Excursion Module shall be equipped with first aid and preventive medicine items for coping with various human injuries and disorders.

3.4.3.7 Environmental Control System.- The environmental control system shall provide the conditioned atmosphere for Life support from two separate recirculating systems as follows:

a. Extravehicular suit environmental control system.

b. Cabin environmental control system.

Additional subsystem design criteria are given below:

3.4.3.7.1 Subsystem Criteria.- These criteria are in addition to those listed in Section 3.2.5.

Water Vapor removal = 9.6 lb/man/day

Extravehicular suit environmental control system is to be considered for emergency operation during lunar rendezvous maneuvers.

3.4.3.7.2 Extra vehicular suit Environmental Control System.- The extravehicular suit environmental control system shall be of the recirculating type and is capable of 4 hours untethered life support for lunar exploration, with recharging capability. The suit and Environmental Control System will be developed under separate specifications.

3.4.3.7.3 Cabin Environmental Control System.- This system will provide an "open face plate" environment in the manned compartment and sufficient ventilation flow to maintain comfort for the pressure suited crew. This recirculating type of configuration enables the crew to open their face plates and remove gloves for increased dexterity. In the event of decompression the crew can "button up", connect the suit bypass, and continue operation unimpeded.

3.4.3.7.4 Oxygen Supply.- Oxygen supply shall be supercritical; however, system shall be serviced with liquid oxygen with allowances for passive heating until just prior to separation in lunar orbit. Additional heat as required will be furnished by electrical heaters at that time to insure supercritical pressure.

3.4.3.7.5 Carbon Dioxide and Odor Control.- Carbon Dioxide and odor control will be provided by LIOH and activated charcoal. The equipment required for return to the orbiting Command and Service Module will be stored in the launch stage with the remainder of the system stowed in the landing stage.

3.4.3.7.6 Crew Comfort.- Crew comfort is maintained by a regenerative heat exchanger and flow diverter valves. Circulation is provided by constant flow redundant blowers. Atmospheric cooling and water condensation is accomplished by a water evaporative heat exchanger. All water collected in the water separater shall be available for cooling purposes.

3.4.3.7.7 Noxious Gases.- Noxious gases, including ozone, methane, hydrogen, carbon monoxide, freon, or other gases emitted from overheated equipment shall be removed to maintain a safe working atmosphere.

3.4.3.7.8 Atmospheric Circulation.- The loop shall be provided with three parallel insolated blowers, any one of which will circulate the required flow. One operating blower shall be capable of supplying the following requirements to both pressure suits simultaneously: Ventilation flow at 3.5 psia shall be 12 CFM thru each suit; maximum flow resistance of each suit shall be 5" of water at 12 CFM, 3.5 psia. Each pressure suit connection shall have a bypass which will permit individual manual flow control.

3.4.3.7.9 Temperature Control.- A liquid coolant heat exchanger system shall be provided to cool the circulating air below the required dew point for condensate removal and humidity control. A regenerative heat exchanger shall be provided for the crew to control their inlet air temperature. A water evaporator shall also be provided for cooling of circulating air in event of loss of coolant.

3.4.3.7.10 Humidity Control.- The condensed water vapor shall be removed by either of two parallel isolated separators. Air-driven centrifugal water separators shall be developed for use. The development of a sponge type water separator shall be pursued until the desired use of the centrifugal separator is unquestioned.

3.4.3.7.11 Thermal Control System.- Passive cooling shall be utilized where possible. An analysis shall be made to determine the optimum method of heat rejection. Expendable refrigeration using water and a recirculating radiator system should be considered with

[redacted]

final selection commensurate with reliability and weight requirements. Systems, subsystems and components critical to the completion of the mission shall not be solely dependent on the cabin atmosphere for heat rejection. Study should include a water management analysis incorporating the Command and Service Module systems.

[redacted]

3.4.3.8 Electrical Power.- The electrical power and distribution system shall supply, regulate and distribute all electrical power required by the Lunar Excursion Module for the duration of its specific mission. The source of electrical power shall be either silver-zinc primary batteries or an open cycle chemical dynamic engine, or combinations of both. The chemical dynamic engine shall be capable of receiving and utilizing residual propellants associated with the propulsion systems. The selection shall be based on considerations of mission profiles, reliability goals, development programs and evidence of tangible weight advantages. Where batteries are employed, the batteries required for lunar liftoff to rendezvous with the Command Module and Service Module will be stored in the launch stage while those required from separation to liftoff will be stored in the landing stage.

3.4.3.9 Communication System.- The on-board communication system shall provide reliable voice communication, telemetry, direct real time television for certain periods on the lunar surface, and a radar for rendezvous and lunar landing.

3.4.3.9.1 Voice Communication.- This subsystem shall provide voice communication capabilities as follows:

a. Between the crew members within or outside the Lunar Excursion Module.

b. Between a crew member within the Lunar Excursion Module and one on the lunar surface at radial distances up to three nautical miles.

c. Between the Lunar Excursion Module and the Apollo Command Module in line-of-sight phases of the mission.

d. Between the Lunar Excursion Module and the earth, and hence to the Apollo Command Module using the earth station as a relay to extend the range of the communication link between the Lunar Excursion Module and Command Module.

3.4.3.9.1.1 To attain the required voice communication capabilities an intercommunication system, a VHF transceiver and a UHF transceiver shall be provided. The VHF transceiver shall be compatible with the Command Module VHF transceiver and the MSC-supplied personal VHF communication system. The UHF transceiver shall be compatible with the DSIF and shall transmit television information as well as voice.

3.4.3.9.2 Telemetry.- All telemetry data transmission is either time shared with the voice or transmitted simultaneously with voice by using subcarriers within and below the voice frequency spectrum. All transmitters and receivers will have the capability of transmitting or relaying this data.

3.4.3.9.3 Television.- Real-time near-commercial quality television transmission shall be provided in conjunction with the UHF transceiver for observing the Lunar Excursion Module crew's activities while on the lunar surface. The Lunar Excursion Module

Associate Contractor shall consider means for providing television transmission of the Lunar Excursion Module launch to the earth.

3.4.3.9.4 Antennas.- A VHF antenna for Lunar Excursion Module - Command Module and Lunar Excursion Module crew member (outside) communication shall be provided. An extendable structural antenna shall be provided for the Lunar Excursion Module-earth UHF link. Provision shall be made to prevent destruction of the UHF extendable antenna during lunar landing and takeoff.

3.4.3.9.5 Jettisonable Items.- The television system shall be left on the lunar surface.

3.4.3.10 Instrumentation.- The instrumentation system shall detect, measure and display all parameters required by the crew for monitoring and evaluating the integrity and environment of the spacecraft and performance of the spacecraft systems. In addition, the capability shall be provided for documenting the mission through photography and recording.

3.4.3.10.1 Measurements.- A tabulation of measurements shall be provided and shall include the number and type of all measurements; sensor characteristics; conditions when taken, (flight, phase, etc.); data disposition, i.e. displayed real time telemetry, recorded for telemetry playback, recorded for storage, etc. A block diagram showing the interrelationship of the instrumentation components shall also be provided.

3.4.3.10.2 Sensors.- The sensors selected for each application shall have an inherent reliability at least one order of magnitude greater than the measured and measuring subsystem and shall be compensated such that their capability to perform the intended function is not degraded by the environmental conditions to which they are subjected. Excitation voltage, where required, shall be standardized, insofar as practicable. In accessible measurement areas shall be provided with both primary and spare sensors and associated auxiliary equipment as required. Electrical leads associated with the sensors shall be electrically shielded and mechanically secured so as to minimize the generation or pickup of noise by the leads.

3.4.3.10.3 Data Disposition.- The capability shall be provided for data transmission upon crew command or onboard programmed command. Provisions shall be made for transmitting data in the following critical areas:

a. Measurements relating directly to conditions having an immediate effect on crew safety.

b. Sufficient measurements in each functional area or system to facilitate failure analysis in event of an unsuccessful flight.

c. Navigation and guidance data as required to permit Command Module checking of vehicle position and course.

3.4.3.10.4 Tape Recorders.- One recorder system shall be provided for the storage of telemetry, voice, and possibly video information for later playback at the discretion of the crew, or for data storage pending spacecraft recovery. This recorder shall also be suitable for use in conjunction with the scientific and biomedical instruments.

3.4.3.10.5 Panel Display Indicators.- The panel display indicator shall not be coupled directly to those data channels which are providing similar information to the telemetry or recording system, i.e., there shall be no coupling between the panel display instruments and telemetry/recording channels which could result in cross effects between the circuits even in event of malfunction.

3.4.3.10.6 Calibration.- A calibration feature shall be provided as an integral part of the measurement system and shall be such as to provide a rapid analytic assessment of the measurement system's performance. The method of calibration shall encompass the overall system where practicable, and in addition shall include selectivity of automatic or manual operation at the crew's discretion.

3.4.3.10.7 Clock.- Redundant, real time, binary code generating devices shall be provided to act as the primary time reference; to correlate all data; and to function as an integral part of all time critical operations. The accuracy and stability of the clock under the environmental conditions expected shall be compatible with the navigation and guidance requirements and needs of scientific experiments. Accurate correlation shall be provided between the Lunar Excursion Module and the Command Module clock systems.

3.4.3.10.8 Partial Pressure System.- This system shall monitor the partial pressure levels of the various constituents in the occupants atmosphere. Redundancy shall be provided for monitoring the oxygen and carbon dioxide partial pressures. These measurements shall be displayed in the vehicle and telemetered to the command module.

3.4.3.10.9 Periscope.- A periscope shall be used to present a view of areas outside the lunar excursion module not covered by the vehicle windows. The periscope shall have a directable field of view which will include the landing pod and crew movements outside the vehicle. Reference axis information shall be provided and recorded when the periscope is used with a camera attachment.

3.4.3.10.10 Cameras.- A camera shall be provided for high resolution still photography of the lunar surface and for use in extra-lunar studies. Accessories shall include a telephoto lens and a telescopic attachment for conversion to a camera telescope configuration capable of infrared and ultraviolet photography. A stable clock driven mount shall be furnished for photography of extra-lunar bodies. Two motion picture cameras shall be provided for on-board photography, one for use with and attachable to the periscope system, shall be supplied to document the movement of the crew on the lunar surface. The other camera shall be suitable for use outside the vehicle. This camera would be jettisoned.

3.4.3.10.11 Radiation Dosimeters.- A radiation spectrometer shall be supplied, complete with computer circuits to calculate radiation dose rates and accumulated dosages in the cabin of the Lunar Excursion Module. Dose rates and accumulated dose shall be displayed in the cabin and telemetered to the Command Module.

3.4.3.11 Scientific Instrumentation.- The scientific instrumentation (supplied by MSC) will provide primarily for selenologic research, but at least part of the system may be useful in the operational instrumentation system or for scientific measurements during portions of the mission other than lunar landing. This system shall consist of portable, self-powered instruments for use outside the Lunar Excursion Module and instruments for use inside the Lunar Excursion Module cabin. Provision shall be made for stowing data packages in the Lunar Excursion Module cabin prior to lunar takeoff, and all equipment not useful on the remainder of the mission shall be jettisoned at that time.

3.4.3.11.1 Lunar Atmosphere Analyzer.- A portable instrument suitable for determining the qualitative and quantitative chemical composition of the lunar atmosphere shall be provided. The data shall be recorded on the Lunar Excursion Module and telemetered to the Command Module. The reduction of data from this instrument shall not require any previous knowledge of the atmosphere composition. This instrument may be the backup system for the cabin atmosphere partial pressure sensing system; otherwise it would be a jettisonable item.

3.4.3.11.2 Gravitometer.- A portable gravitometer shall be supplied for the determination of the direction and magnitude of the moon's gravitational field at the lunar surface. This is a jettisonable item.

3.4.3.11.3 Magnetometer.- A portable instrument for the determination of the direction and magnitude of the lunar magnetic field shall be provided. This is a jettisonable item.

3.4.3.11.4 Radiation Spectrometer.- A portable radiation spectrometer shall be provided for measurement of the radiation spectrum at the lunar surface. A means should be provided for differentiating between seleno-original radiation (e.g. natural radioactivity), and solar and cosmic radiation. Data should be recorded on the Landing Excursion Module and telemetered to the Command Module. This system shall contain a telemetry system for direct to earth telemetry, powered by solar cells, and will be left on the lunar surface for extended use in monitoring solar and cosmic ray radiation.

3.4.3.11.5 Specimen Return Container.- A small container shall be supplied to be filled with lunar material. This container shall seal after filling in a manner such that no material, gaseous, solid, or bacterial can enter the container during the return mission.

3.4.3.11.6 Rock and Soil Analysis Equipment.- Simple equipment shall be supplied suitable for obtaining samples of lunar surface material for analysis, examination, or return to earth. This equipment is jettisonable.

3.4.3.11.7 Microscopic Camera System.- A camera system with microscopic attachment shall be supplied suitable for examination of lunar soil and/or rocks inside the Lunar Excursion Module cabin. The equipment will aid in the selection of samples for earth return and in photographing discarded specimens. The camera may be used for other purposes also; the microscopic attachment is jettisonable.

3.4.3.11.8 Coreing Equipment.- Apparatus for obtaining samples of the lunar material lying at least five feet below the surface shall be supplied. Samples obtained will be handled in the same manner as surface soil and rocks. This apparatus is jettisonable.

3.4.3.11.9 Seismographic Equipment.- Seismographic equipment shall be supplied for investigating the sub-surface structure of the moon. The equipment shall consist of acoustic exciters and detectors, which are jettisonable items. Data should be recorded in the Lunar Excursion Module.

3.4.3.11.10 Soil Temperature Sensors.- Probes suitable for measuring lunar surface and sub-surface temperatures shall be provided. Probes shall be suitable for measuring temperatures at depths up to three feet, in case the lunar soil permits such penetration. Probes may be connected by hard line to the Lunar Excursion Module and data may be processed by the operational onboard instrument system. Data should be recorded in the Lunar Excursion Module; the probes are jettisonable.

3.4.3.11.11 Cameras and Telescopes.- The onboard operational camera-telescope system will be used for scientific purposes while on the lunar surface.

3.4.3.11.12 Other Scientific Instruments.- Other scientific instruments will be supplied by MSC as requirements for these items mature.

3.5 Mission Control Center (MCC) and Ground Operational Support System (GOSS).- The design configuration of the Mission Control Center and the ultimate design configuration of the Ground Operational Support System have not yet been established. This section describes the operational concept for the Mission Control Center and the computational facilities, gives a general description of the initial configuration of the Ground Operational Support System, and a general outline of the ultimate configuration as currently visualized. Existing facilities such as the Mercury network and the DSIF, both appropriately modified, will probably be used in the Apollo program.

3.5.1 General Description.- Overall control of all Apollo support elements throughout all phases of a mission will be accomplished from a Mission Control Center (MCC). Mission launch activities up to the time of liftoff will be conducted from a launch control center, at Cape Canaveral. In addition to the launch control center, two types of remote stations will be used. The first type of station will provide support for the following communications: voice, telemetry reception and data processing, data transmission from the ground to the Spacecraft, tracking to determine Spacecraft position and velocity with appropriate data processing and an acquisition system for antenna pointing. Initially the ground support for earth-orbital flights will be supported by modified Mercury-type stations to support the diversified use of frequencies in the VHF and C-Bands, with the contemplated use of the DSIF UHF frequency band for lunar distance communications. It is visualized that eventually some of the Mercury-type sites will be modified or new sites will be implemented to operate using a unified UHF frequency which will support all voice, telemetry, television, and ranging information for near-earth and lunar distances. In the proposed unified concept antenna changes will be required at the existing Mercury sites to enable those sites to have both near-earth and lunar distance capabilities. However, the DSIF would have no role in the near-earth and earth-orbital missions. The second type of remote station will be equipped for use in tracking the Command Module during reentry. Some new stations will probably be required, particularly to provide tracking during reentry. These stations will be located both on land and on ships. The remote stations will be connected to the communications and computation centers located in the Mission Control Center by landlines, submarine cables, and/or by radio, depending on the location of the remote stations. A station will be located at the NASA-Manned Spacecraft Center at Houston. This station may be used for Spacecraft-GOSS equipment compatibility checks, simulated missions, astronaut-ground procedure training, development of network operational procedures, as well as for actual missions.

3.5.1.1 Mission Control Center.- The Mission Control Center will have the capability of monitoring the Spacecraft and directing the support elements for all phases of Apollo missions including unmanned and manned earth-orbital and translunar flights. In addition, this control center will include the simulation and training facilities associated with the Spacecraft and the GOSS. These simulation and training facilities include the Apollo crew trainer coupled into the Mission Control Center and simulated remote stations located adjacent to the Mission Control Center. This will combine crew and Mission Control Center personnel training and procedural development.

The Mission Control Center will include a communications center and the appropriate data processing equipment and displays required to allow complete and adequate control of the mission information flow. The Mission Control Center will also include the computing facilities that will be required to handle the data processing required for the determination of vehicle position and velocity and other associated computations throughout the flight phase of the mission.

The information flow associated with the Mission Control Center will include voice communication capability to and from the Spacecraft via relay through any of the remote stations, the transmission of information to the Spacecraft (this may be direct commands for unmanned Spacecraft or for assimilation by the crew of manned Spacecraft), the reception of processed vehicle telemetry data from the GOSS stations, the control and conduct of the GOSS, and all tracking and tracking support data.

3.5.1.2 Launch Control Center.- Launch control, including space vehicle preparation and checkouts, and the launch countdown will be conducted from Cape Canaveral. Launch control center facilities include the displays and communications necessary for monitoring of the progress of the mission countdown and powered flight phase.

3.5.1.3 Remote Station.- The ground transmitted signal will include voice (relayed from MCC if desired), coded information and beacon or transponder interrogation. The Spacecraft transmission and subsequent ground systems reception will include voice, down telemetry, and beacon or transponder response. It is anticipated that as the program advances the RF link between the Spacecraft and the GOSS may transgress from initial HF, VHF and C-Band links to a single UHF link. The basic site equipment includes an automatic data processor which controls the information flow through the site. Where suitable point-to-point communication circuits exist, the voice information is relayed to the MCC. The telemetry and tracking information is recorded on tape units and simultaneously fed into the data processor where the information is selected by established ground rules and/or MCC directives.

The site data processor, in addition to accepting and reprocessing telemetry and tracking data, also deals with information received from the MCC and from the local inputs and delivers it to acquisition consoles, TTY and higher-speed data transmission systems, and to local visual displays.

Acquisition methods and aids will be provided for acquiring the Spacecraft in angle, frequency, and range. Simulation aids for local training and exercises will be provided for the RF systems and for the communication components. Each of the remote ground stations with the exception of the reentry, may eventually be capable of a significant communications and tracking capability at lunar distances. Thus, loss of any station is not catastrophic since alternative lunar capability will exist at other stations.

An interim period will exist before the achievement of the contemplated GOSS for Apollo from the current ground equipment employing Verlort and AN/FPS-16 radars, FM/FM VHF telemetry and UHF voice. The transition from the Mercury-type of equipment to the unified frequency system-equipment should be made consistent with the Apollo systems development and the Apollo program schedules. The current system will remain substantially unchanged if project schedules for the early Apollo vehicles must carry extensions of the Mercury system.

3.5.1.4 Remote Station Equipment.- Current equipment plans for each ground station includes the use of UHF and VHF communications systems, the use of C-band equipment for near-earth tracking, and the use of UHF transponders for tracking at lunar distances. The unified RF systems concept utilizes a single UHF frequency for both near-earth and lunar communications and tracking.

The unified systems concept requires that the RF modulation techniques used in a single RF UHF carrier bandwidth will be the same for both earth-orbital and lunar missions. The remote station configuration provides an antenna installation supporting two RF information channels (not widely separated) in the same frequency band. These information channels would be used for position and velocity determination, voice, and telemetry. The functional layout of the remote site is shown in figure 77, and figure 78 indicates the type and kinds of data flow that occur in the site.

APPENDIX B

INSTRUCTIONS AND REQUIREMENTS FOR PHOTOGRAPHIC DOCUMENTATION

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INSTRUCTIONS AND REQUIREMENTS FOR PHOTOGRAPHIC DOCUMENTATION

1. PHOTOGRAPHY.- The Contractor shall accomplish still and/or motion picture photography on both a continuing and an "as negotiated" basis as indicated herein. Photographic coverage shall include documentation of highlight aspects of research and development, facilities construction and utilization, hardware fabrication and production, ground test activities, including rapid sequence and high-speed engineering sequential motion picture coverage of appropriate test phases, and related events and subjects involving the Contractor's area of responsibility.

2. OBJECTIVE.- The objective of the photographic coverage specified herein is to satisfy a continuing NASA - MSC need for documentation and reporting of the Contractors research and development activities and progress. The still and/or motion picture coverage thus obtained will be used for purposes of program evaluation and management analysis, written report backup, and the preparation of training, orientation, and briefing films. Other uses include legal, historical, and the fulfillment of various information services requirements.

3. STANDARDIZATION. - For purposes of compatibility and in the interest of economy in reproduction, it is necessary to standardize in the type of original films used by the various producers and contractors. For normal motion picture photography (16 mm, 24 f.p.s.) Eastman Ektachrome Commercial type 7255, or equivalent, is recommended. When light conditions prevent the use of this film, Ektachrome ER type 7257 (daylight), or Ektachrome ER type 7258 (tungsten), or equivalent, may be used. These high-speed emulsions (ASA 160-120) should be used only when absolutely necessary, as some quality losses result in duplication.

4. GENERAL MOTION PICTURE AND STILL PHOTOGRAPHIC SPECIFICATIONS.- These instructions outline specifications for motion picture photography and the still picture documentation required. Changes to these specifications may be made only with the approval of the Contracting Officer.

a. Motion picture specifications:

(1) As a general rule, original motion picture photography shall be in 16-mm Ektachrome commercial, or equivalent, exposed at 24 frames per second. The use of 35-mm color film must be specifically authorized by the Contracting Officer. Black-and-

white film and other frame-rates may be used in instances where the capability of the color film or the normal frame-rates would be detrimental to the accomplishment of specialized photographic coverage, such as aerial, engineering sequential, and time-measurement photography.

(2) The Contractor shall not project or cut original film exposed in connection with the Contract, except to eliminate waste film caused by camera failure or faulty photographic techniques (gross over or underexposure, over or underdevelopment, out-of-focus, etc.) which results in qualitatively unsatisfactory film. Unusable heads and tails of scenes and unselected takes may be retained by the Contractor on file or destroyed at the Contractor's discretion.

(3) All original camera film footage shall be slated whenever possible. Slate information shall include, as appropriate: Contractor identification, project number and/or name, Contract number, security classification, date photographed, scene and take number. Two copies of caption information describing the action involved in each scene and the significance of the sequence of which the individual scene is a part, shall be forwarded with all original camera film footage submitted to the NASA-Manned Spacecraft Center, Apollo Spacecraft Project Office. All individual reels of film footage will bear head and tail security classification leaders.

b. <u>Still Picture Specifications</u>:
All still photography will be of professional quality and in a quantity that will meet the needs of both the NASA and the Contractor for scientific, technical and reporting data required in support of the assigned research and development effort.

(1) As a general rule, the still photography shall be accomplished on 4 x 5 inch black-and-white film, 4 x 5 inch negative or reversible color film may be used in those instances where it is deemed essential to record and present the subject matter distinctly and accurately and for significant highlight events such as roll-outs, mockups, etc. The original camera raw stock film shall be of a type determined by the contractor to be best suited to the recording objective under the prevailing environmental conditions of each photographic assignment.

(2) The following data shall be lettered in ink on the clear margin of each original negative or color transparency on the acetate side starting from the left: negative number, date, contractor, and classification.

(a) The negative number: This shall start with numeral 1 (one) for the first photograph of the calendar year on each specific contract of which the photographic coverage is a part.

(b) The date shall consist of numerals for the day of the month, followed by the abbreviated name of the month followed by the last numerals of the calendar year.

(c) Contractor's and subcontractors' name if applicable, abbreviated, shall follow the date of photography.

(d) If the photograph is classified, the classification shall follow the contractor's name. A typical negative marking would be as follows: 120/14 JUL 62 (Contractor's name)/Confidential.

(e) Each negative or color equivalent shall be placed in a separate negative preserver. A contact print of the negative shall be attached to the front of the envelope (to assure minimum handling of the negative). The negative identification data shall be marked on the preserver, starting in the top left front corner. In addition the preserver shall be conspicuously marked with the proper classification in accordance with DOD Industrial Security Manual, Section II, Handling of Classified Information.

(f) A written caption shall be prepared for each negative produced and forwarded under terms of this Contract. This information must include the who, what, when, where, and why type of data as well as other pertinent facts, including the specific date the photograph was taken. If nicknames are used, explain their meaning. The caption may be typed on a sheet of paper and placed inside the negative preserver, or attached to the back of the envelope. The captions shall be double spaced.

(g) The negative identification data specified above shall be reproduced on all prints made. This reproduction may be accomplished by any means available which will insure a permanent record of the identification data on each print, such as: photographic reproduction through the negative; by typing, waterproof ink lettering, ditto, or rubber stamp. In addition to the identification data, the front of each classified print shall be stamped with the appropriate classification (in the white border) at the top and bottom and on the back.

5. <u>MOTION PICTURE REQUIREMENTS:</u>

a. Documentation.- The Contractor will accomplish motion picture coverage of significant highlight events within the area of his activity, as they occur, and which are essential to the fulfillment of the NASA-MSC's need for engineering, evaluation, and Management data, or for reporting purposes. This coverage will include the unsuccessful and unfavorable events as well as the positive aspects of the Contractor's activity and progress.

b. Film Clips.- The Contractor shall accomplish additional motion picture coverage as required for the preparation of film clips as directed by the MSC Apollo Spacecraft Project Office. Subject matter of this film footage will include coverage of special happenings such as mockups, development test activities, and other events which depict the program progress and status. Footage suitable for use in the various NASA-MSC film reports must portray a complete story of a specific research and development event, phase, or activity. The photographic coverage should include a variety of scenes of the reported item or event, i.e., establishing shots, medium shots, close-ups, and cutaways, to assist the NASA film editor in telling the story. The film footage should consist of full length, unedited, untitled, silent scenes of sufficient length to provide 5-10 minutes running time as received from the Contractor.

c. Special Film Requirements.- The production of briefing, concept, indoctrination films, and special animation sequences may be assigned to the Contractor from time to time by the Contracting Officer. The production of these special film reports will be subject to contract negotiation.

6. STILL PHOTOGRAPHIC REQUIREMENTS.- The Contractor shall accomplish still photographic documentation of all significant highlight events within the area of his activity and responsibility as they occur and as he determines is essential to the fulfillment of MSC's and the Contractor's need for engineering, evaluation, management data, and reporting purposes. "Special Interest" highlight events shall be accomplished in color as specified in paragraph 4(b). Routine documentation will be done in black and white.

7. TRANSMITTAL OF PHOTOGRAPHIC MATERIALS:

a. Motion Picture Film

(1) All of the original motion picture footage produced and costed under terms of this Contract, is the property of

the NASA. Unless otherwise specified, the Contractor will forward all original motion picture material produced under this Contract to NASA-Manned Spacecraft Center, Apollo Spacecraft Project Office. Written information describing the activities and items shown in the film will accompany each shipment of film.

(2) When the Contractor produces films other than those specified and/or requested by the Contracting Officer, utilizing film footage exposed and costed under this Contract, it shall be at no expense to NASA. When such films are used for public release purposes by the Contractor, they shall be reviewed by and receive final approval in writing from NASA-Manned Spacecraft Center before being released for exhibition. Requests for release of such Contractor sponsored films, including a viewing print of each, will be forwarded to the Apollo Spacecraft Project Office, NASA-Manned Spacecraft Center.

(3) All classified motion picture film footage and completed film reports produced under this Contract shall be handled in accordance with the provisions of DOD Industrial Security Manual, Section II, Handling of Classified Information. The original film and two prints which are made from the original and which match frame for frame will be submitted. In addition, two copies of written information describing the activities, and items shown in the film footage, will be forwarded by the Contractor to the NASA-Manned Spacecraft Center, Apollo Spacecraft Project Office.

b. Still Pictures.

(1) The black and white or color negative or color transparency, together with a contact print (of the black and white negative only) and two 8-1/2 x 11" enlargements of the black and white negative shall be forwarded to the MSC Apollo Spacecraft Project Office.

[redacted]

TABLE I LUNAR EXCURSION MODULE MASTER PHASING SCHEDULE

MAJOR EVENT	1962				1963				1964				1965				1966				1967				1968			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
CONTRACT GO AHEAD			△																									
INITIAL PROGRAM PLAN				△																								
INITIAL PERFORMANCE SPECS				△																								
MOCK-UP COMPLETE							△																					
FIRST PROPULSION SYS PERT												△																
FIRST TEST ARTICLE MFG COMPLETE													△															
FIRST TEST ARTICLE FLIGHT, LJ II														△														
FIRST HOVER & LANDING FLT TEST																△												
FIRST COMPLETE LEM FLT TEST																△												
LEM DEV & QUAL FOR LUNAR MISSIONS COMPLETE																					△							
LUNAR MISSIONS																					▬	▬	▬	▬	▬	▬	▬	▬

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TABLE II DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery* (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.1.2	Document Revision Methods	1	As required	I	5** 20***
4.5.2.1.1	Ground Support Equipment Performance and Interface Specifications	2	As required	I	50** 100***
4.5.2.1.2	Lunar Excursion Module Subsystem Specifications	4	As required	I	50** 100***
4.5.2.1.3	Material, Parts, and Process Specifications	15 days	As required	II (New Specs) III (Existing Specs)	50
4.5.2.1.4	Mockup Specifications	2	As required	I	50** 50**
4.5.2.1.5	Training Equipment Specifications	4	As required	I	50** 100***
4.5.2.1.6	Final Specifications	6 months after completion of all other technical contractural requirements		I	5** 1*** (reproducible)

* Initial delivery requirements are shown as time after date of contract, unless otherwise noted.
** Prior to NASA approval.
*** Subsequent to NASA approval.

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.3.1.1	Program Plan	2	As required	I	100** 200***
4.5.3.1.2	Facilities Plan	2	As required	I NASA approval required prior to implementation	50** 100***
4.5.3.1.3	Test Plan	2	As required	I	50** 100***
4.5.3.1.4	Manufacturing Plan	2	As required	I	50** 100***
4.5.3.1.5	Part I: Reliability Program Plan	2	As required	I	50** 100***
	Part II: Reliability Test Plan	2	As required	I	50** 100***
4.5.3.1.6	Maintenance Plan	2	As required	I	50** 100***
4.5.3.1.7	Support Plan	2	As required	I	50** 100***
4.5.3.1.8	Training Plan	2	As required	I	50** 100***
4.5.3.1.9	End Item Test Plan	5	As required	I	50** 100***

** Prior to NASA approval
*** Subsequent to NASA approval.

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.3.2	PERT Reports	As required	Biweekly	II	1 (TWX)
4.5.3.2.1	PERT Events Document	2	As required	II	100
4.5.3.3	Monthly Financial Management Reports	10 days after end of first month	10 days after end of each interim month; 15 days after end of each quarter	II	25
4.5.3.4	Hardware List	1	As required	I	50** 100***
4.5.3.5	Mockup Inspection Plan	4	As required	I	25** 50***
4.5.4.1	Monthly Progress Report	10 days after end of first month	10 days after end of month for first two months of each calendar quarter	II	100
4.5.4.2	Quarterly Progress Reports	10 days after end of first calendar quarter	10 days after end of each calendar quarter	II	100

** Prior to NASA approval
*** Subsequent to NASA approval

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.4.3	Final Report	6 months after completion of all other technical contractual requirements		II	5 (1 reproducible)
4.5.4.4	Weekly Launch Site Activities Reports	2 days after end of first week of operation at launch site	2 days after end of each week	II	100
4.5.4.5	Monthly Weight and Balance Reports	10 days after end of first month	10 days after end of each month	II	50
4.5.4.6	Emergency Action Reports	As required		II	20
4.5.4.7	Quarterly Reliability Status Report	1 month after end of first calendar quarter	1 month after end of each calendar quarter	II	20
4.5.4.8	Still Photographs	Contractor: 12 days after exposure, submitted weekly. Subcontractors: 20 days after exposure, submitted weekly		II	1 B/W Print Negative 2 ea. $8\frac{1}{2}$x11" enlargements

** Prior to NASA approval
*** Subsequent to NASA approval

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.4.9	Motion Picture Photography				
	Documentation	Contractor: 20 days after shooting * Subcontractor: 30 days after shooting *		II	Original plus 2 prints
	Film Clips	15 days after completion of shooting		II	Original plus 2 prints
4.5.4.10	Lunar Excursion Module Flight Reports	1 month after each flight	-	I	50** 200***
4.5.4.11	Lunar Excursion Module Equipment Status Report	12	As required	II	10
4.5.4.12	Program Management Plan Reports				
	a. Milestones	1	Every 12 weeks	I	20** 50***
	b. Schedule Dates	15 days after approval of milestones	Biweekly on Wednesday	II	1 (TWX)

* Certain film footage exposed for engineering sequential and metric data purposes may be held longer than the days specified with written notification including anticipated delivery date.

** Prior to NASA approval

*** Subsequent to NASA approval

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.5.1	Technical Data, Reports and Analyses	2 weeks after completion of each block of effort or logical subdivisions thereof	-	II	20
4.5.5.2	Design Information	As required	-	II	20
4.5.5.3	Materials Reports	1 month after end of second calendar quar-ter	Subsequent Reports 1 month after every other calendar quarter. Final report 2 months after completion of the work for the final period of the contract	II	20
4.5.6.1	Qualification Status List	6	As required	II	20
4.5.6.2	Qualification Test Reports and Data	1 month after each test series		II(Reports) III(Data)	20
4.5.6.3	Failure Data	5 days after failure	As required	II	2
4.5.6.4	Monthly Failure Summary	10 days after sixth month	10 days after end of each month	II	10

** Prior to NASA approval
*** Subsequent to NASA approval

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.7.1	Acceptance Test Data Sheets	15 days after each test series	-	II(Major Components) III (all others)	20
4.5.7.2	Data and Reports on other Tests	1 month after each test or test series	-	II(Reports) III(Data)	10
4.5.7.3	Special Sampling Plans	1 month prior to use	As required	I	5** 10
4.5.7.4	Quality Control Plan	2 months	As required	I	50** 100***
4.5.7.5	Inspection, Measuring and Test Equipment procedures	1 month prior to use	As required	II	10
4.5.7.6	Monthly Quality Report	10 days after end of twelfth month	10 days after end of each month	II	20
4.5.7.7	Quarterly Summary of Quality Control Performance Audit	15 days after end of fourth quarter	15 days after end of each calendar quarter	II	20

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.7.8	Inspection and Test Procedures	1 month prior to each test series	-	II	20
4.5.7.9	Process Control Procedures	2 weeks prior to intended use	As required	II	20
4.5.7.10	Storage Procedures for End Items	2 weeks prior to intended use	As required	II	20
4.5.7.11	Application of Sampling Plans	2 weeks prior to intended use	As required	II	20
4.5.8	Drawings	As requested	As requested	II	As requested
4.5.8.2	Final Drawings	6 months after completion of all other technical contractual requirements		II	1(Microfilm)
4.5.8.4	Drawing List	3	Biweekly	II	20
4.5.9.1	Checkout Manuals	6	As required	I	20** 50***
4.5.9.2	Lunar Excursion Module Operations Manuals	6	As required	I	20** 50***

** Prior to NASA approval

*** Subsequent to NASA approval

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DOCUMENTATION TYPE AND DELIVERY SCHEDULE

Requirement Paragraph No.	Item	Initial Delivery (Months)	Subsequent Issues or Revisions	Documentation Type	Approximate No. of Copies
4.5.9.3	Lunar Excursion Module Flight Operation Manuals	6	As required	I	50** 100***
4.5.9.4	Maintenance and Repair Manuals	6	As required	I	20** 50***
4.5.9.5	Lunar Excursion Module Familiarization Manual	4	As required	I	50** 250***
4.5.9.6	Ground Support Equipment Manuals	6	As required	I	50** 100***
4.5.9.7	Description Manuals	4 months prior to each launch	As required	II	100
4.5.9.8	Transportation and Handling Manuals	6	As required	I	20** 50***
4.5.9.9	Training Manuals	6	As required	I	50** 100***

** Prior to NASA approval
*** Subsequent to NASA approval

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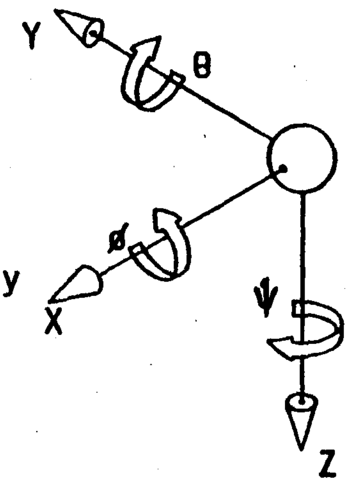
Positive directions of axes and angles (forces and moments) are shown by arrows. (when launch vehicle is at a launch angle of 90°, the positive "X" direction in vertically upwards.)



Axis		Moment about axis		
Designation	Sym-bol	Designation	Sym-bol	Positive direction
Longitudinal	X	Rolling	L	Y ⟶ Z
Lateral	Y	Pitching	M	Z ⟶ X
Normal	Z	Yawing	N	X ⟶ Y

Force (parallel to axis) symbol	Angle		Velocities	
	Designation	Sym-bol	Linear (compo-nent along axis)	Angular
X	Roll	ø	u	p
Y	Pitch	θ	v	q
Z	Yaw	ψ	w	r

Figure 1.- Reference axis system.

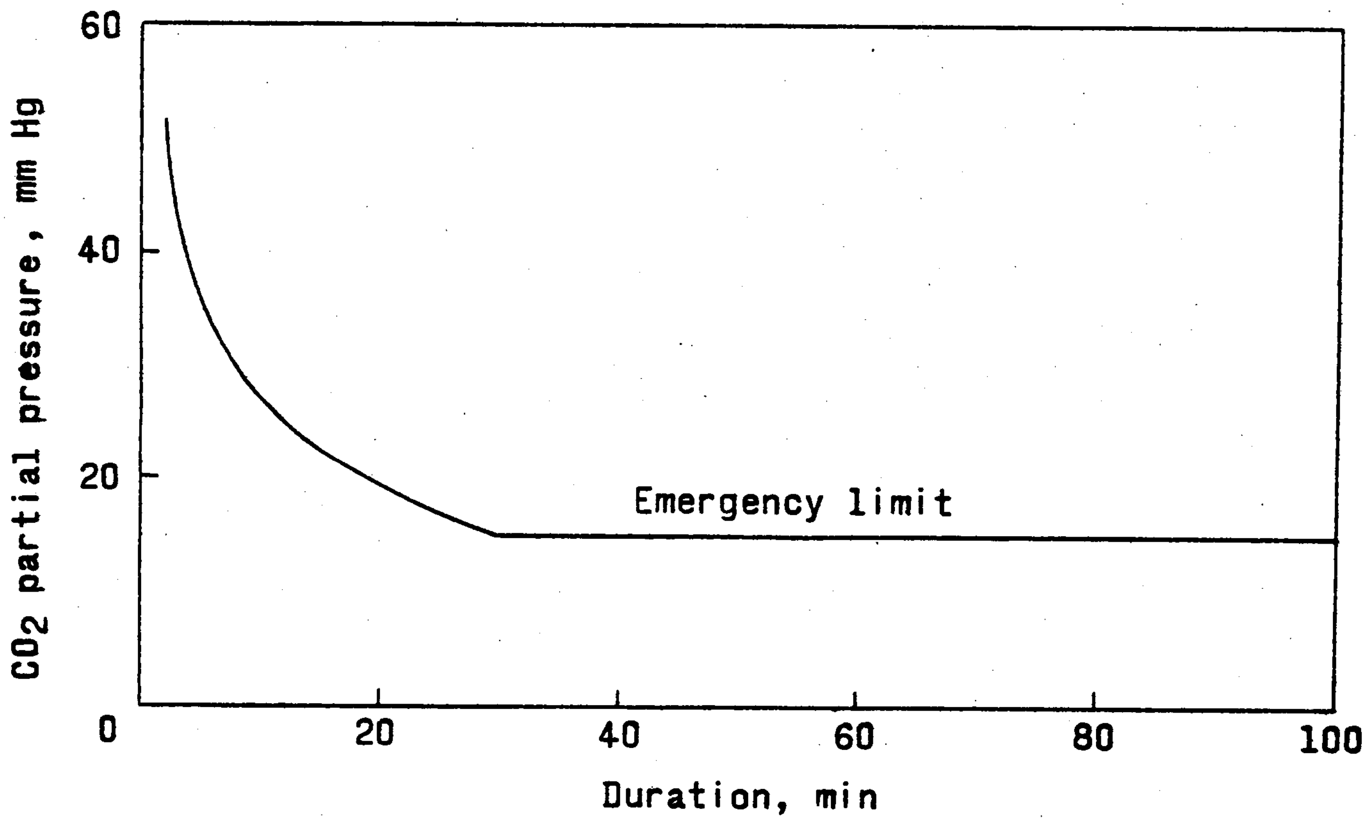


Figure 2.- Emergency carbon dioxide limit.

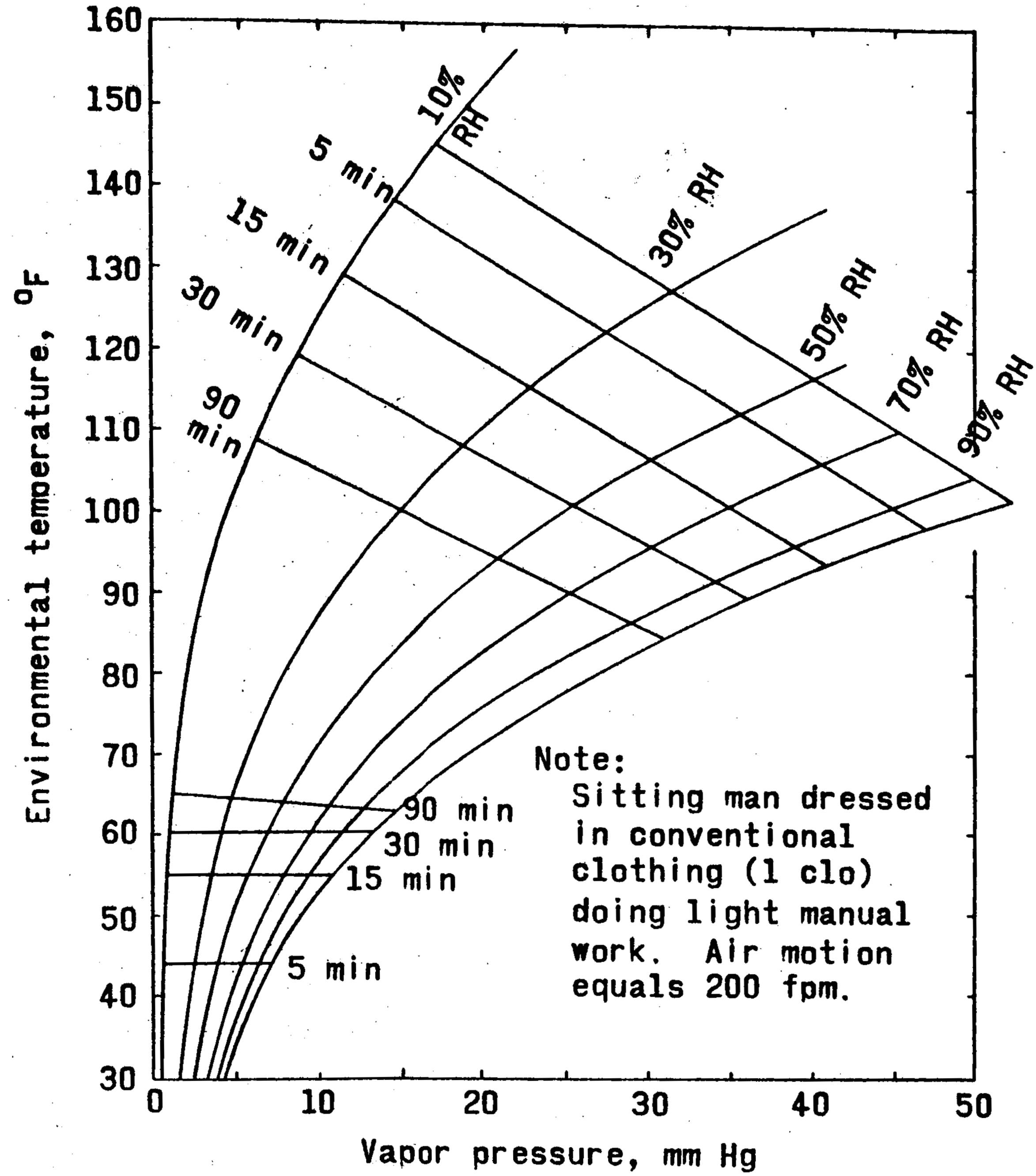


Figure 3.- Temperature and humidity nominal limit.

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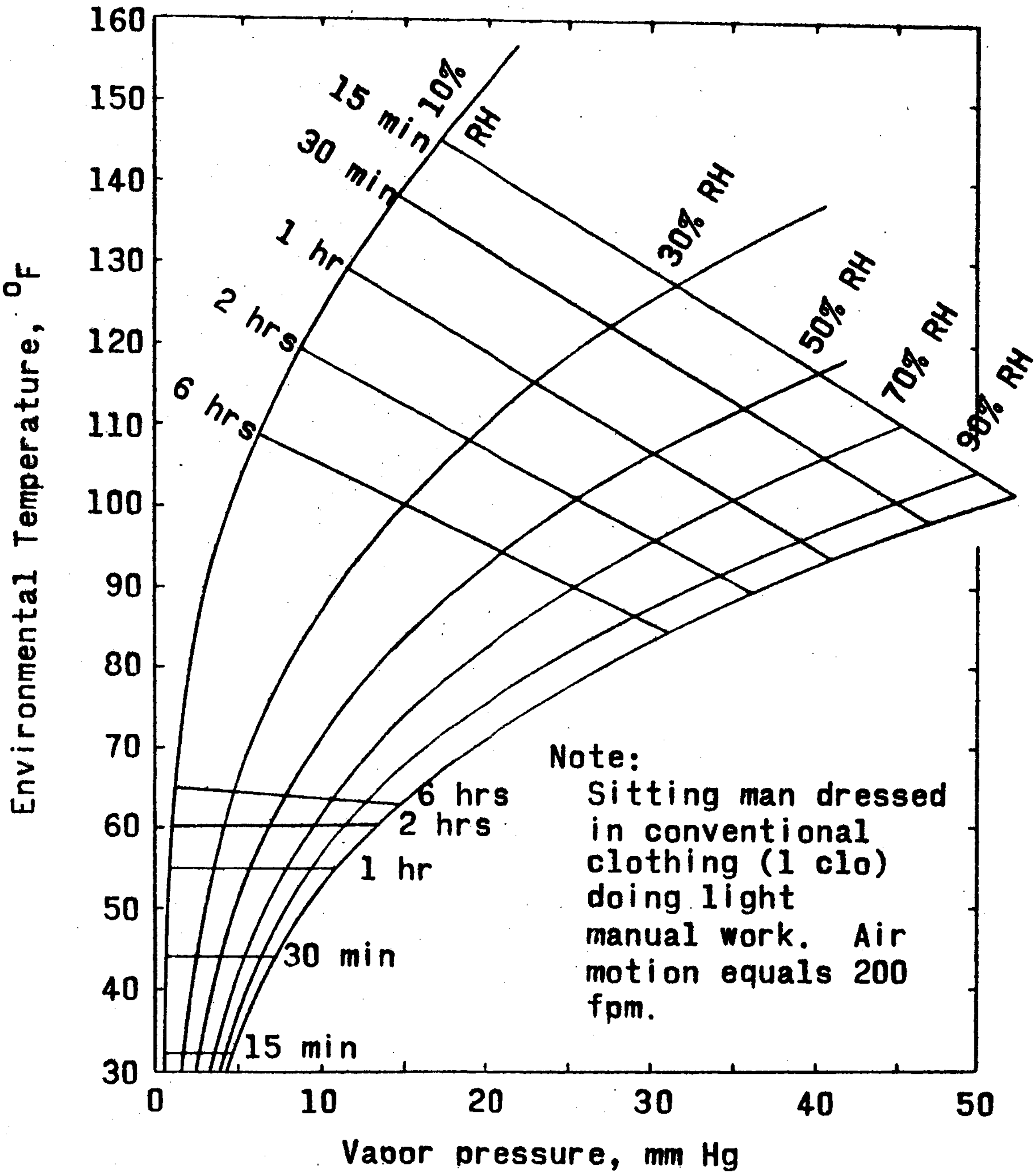

Figure 4.- Temperature and humidity emergency limit.

[redacted]

Critical organ	Maximum permissible integrated dose (rem)	RBE (rem/rad)	Average yearly dose (rad)	Maximum permissible single acute emergency exposure (rad)	Location of dose point*
Skin of whole body	1,630	1.4	233	500[1]	0.07-mm depth from surface of cylinder 2 at highest dose rate point along eyeline
Blood-forming organs	271	1.0	54	200	5-cm depth from surface of cylinder 2
Feet, angles, and hands	3,910	1.4	559	700[2]	0.07-mm depth from surface of cylinder 8 at highest dose point
Eyes	271	2[3]	27	100	3-mm depth from surface on cylinder 1 along eyeline

*See figure 6.

[1]Based on skin erythema level

[2]Based on skin erythema level but these appendages believed to be less radiosensitive

[3]Slightly higher RBE assumed since eyes are believed more radiosensitive

Figure 5.- Radiation exposure dose limits.

[redacted]

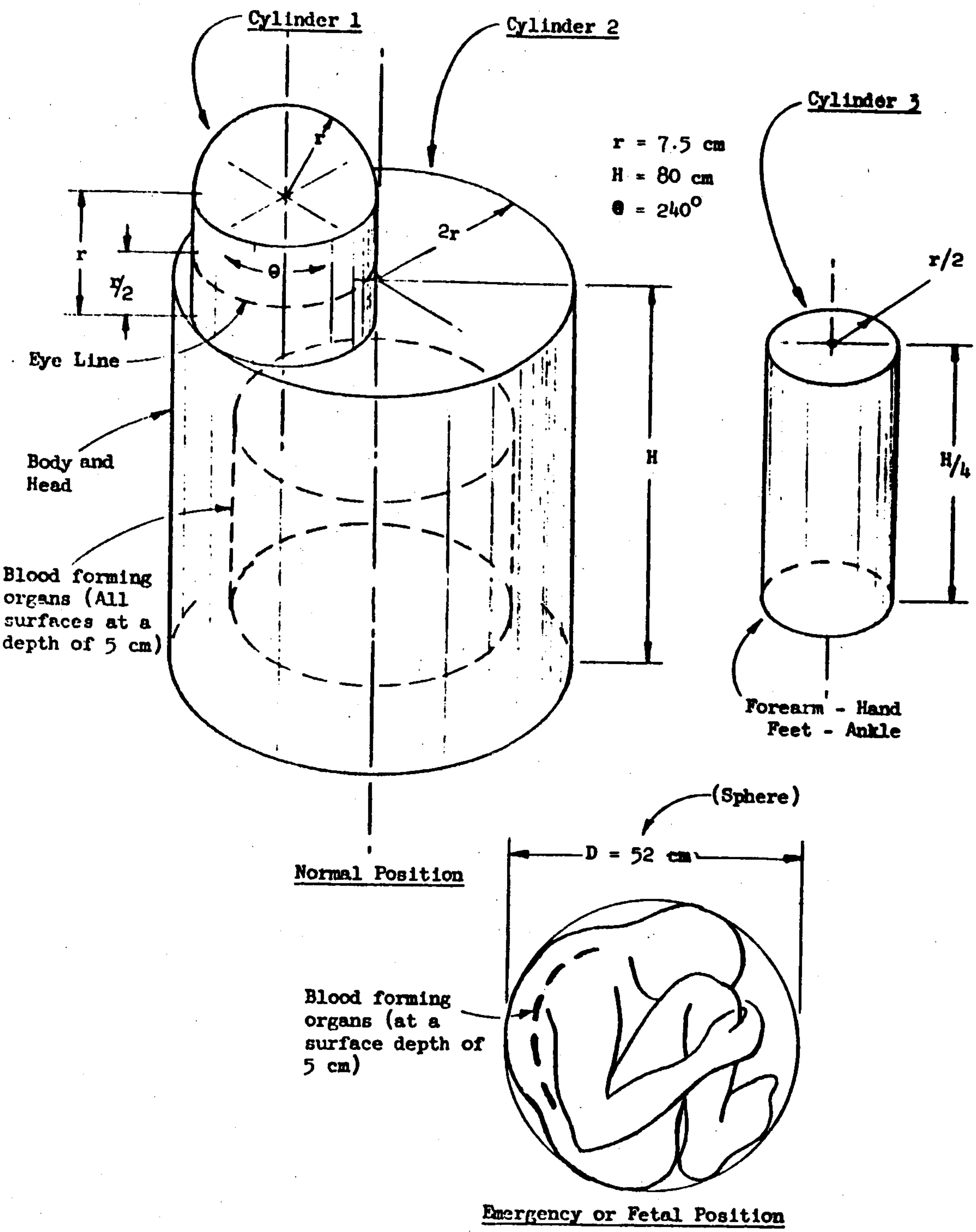

Figure 6.- Models of the radiation standard man.

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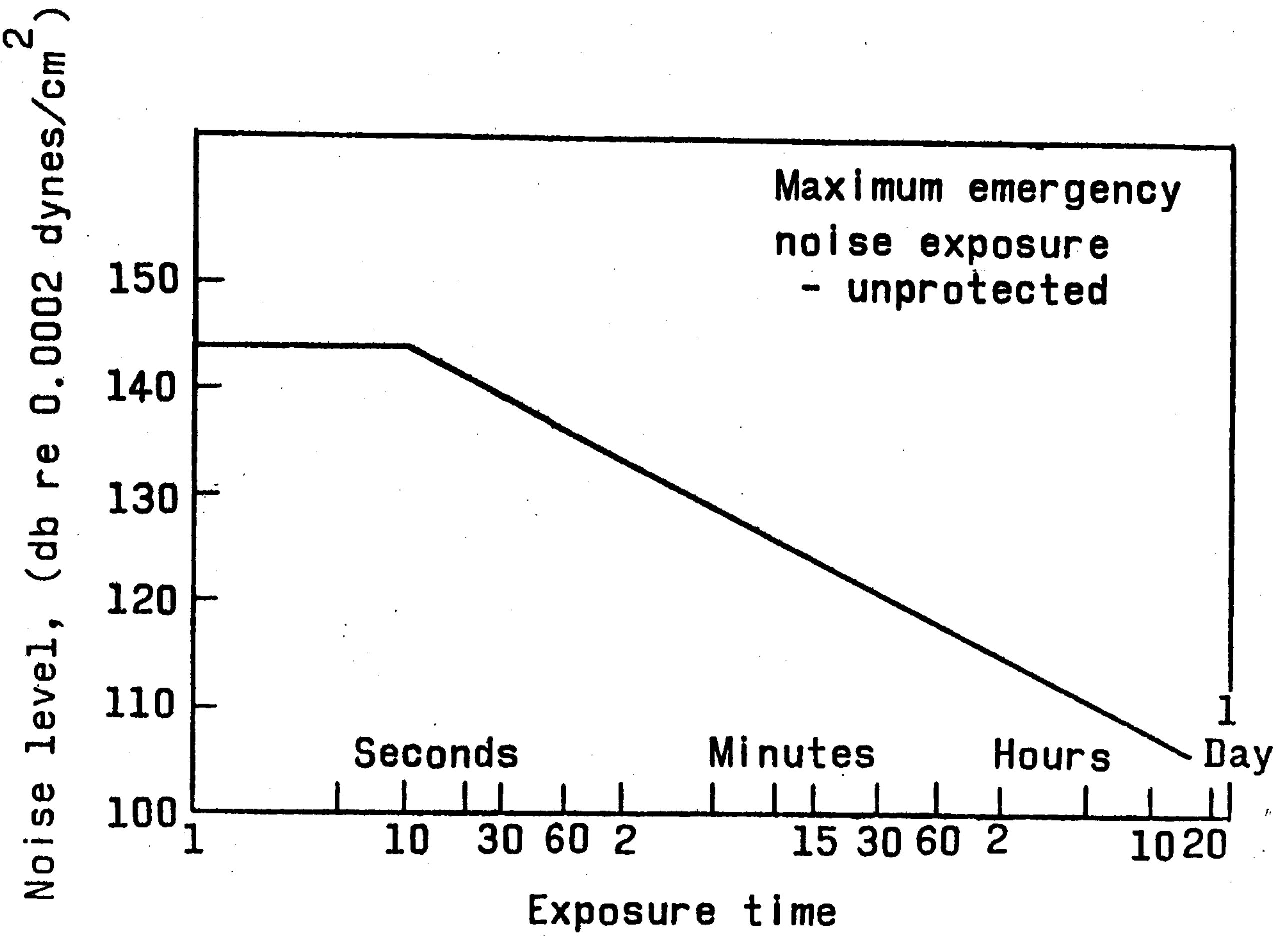

Figure 7 .- Noise tolerance, emergency limit.

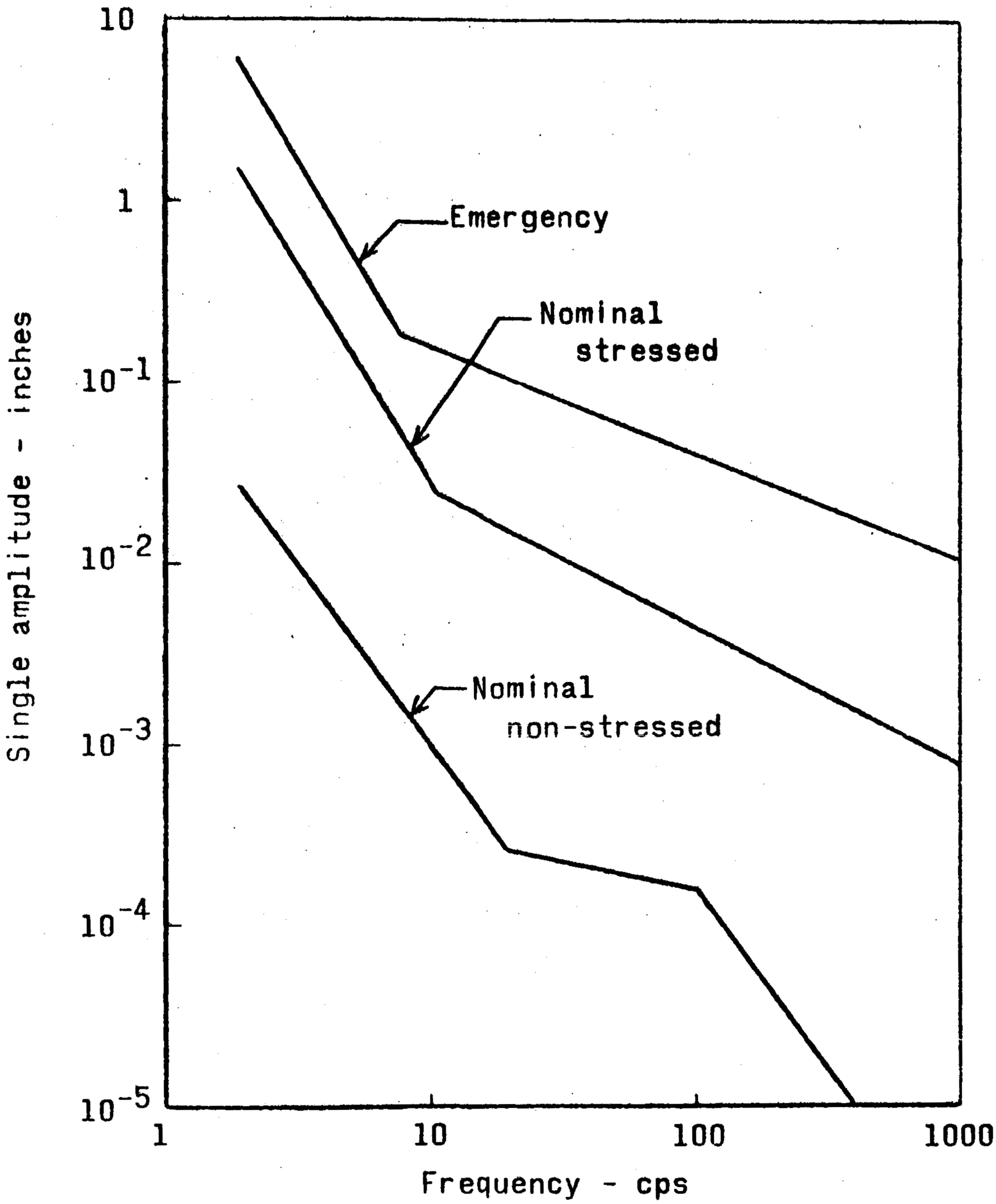

Figure 8.- Vibration limits.

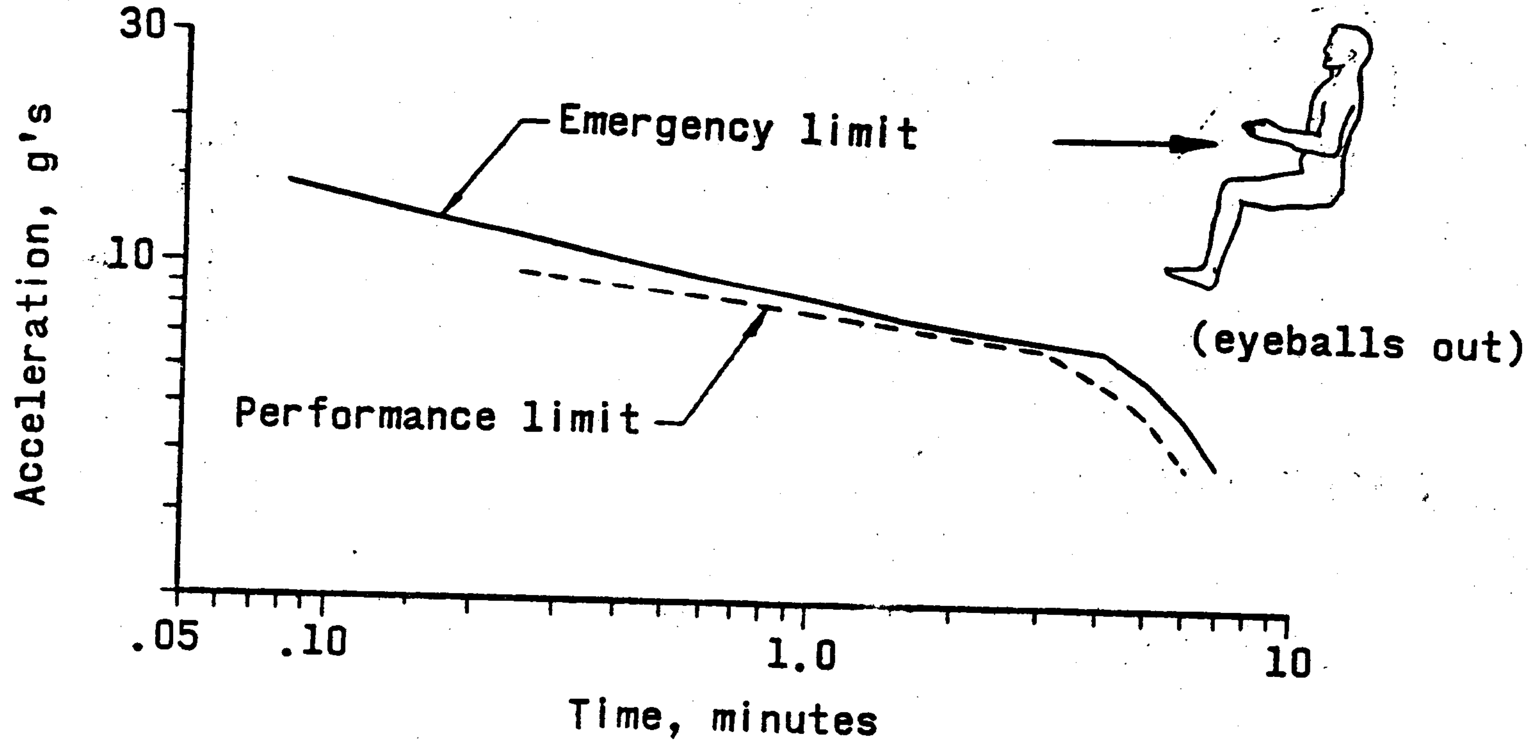

Figure 9 .- Sustained acceleration. (References 1 thru 4 and 7).

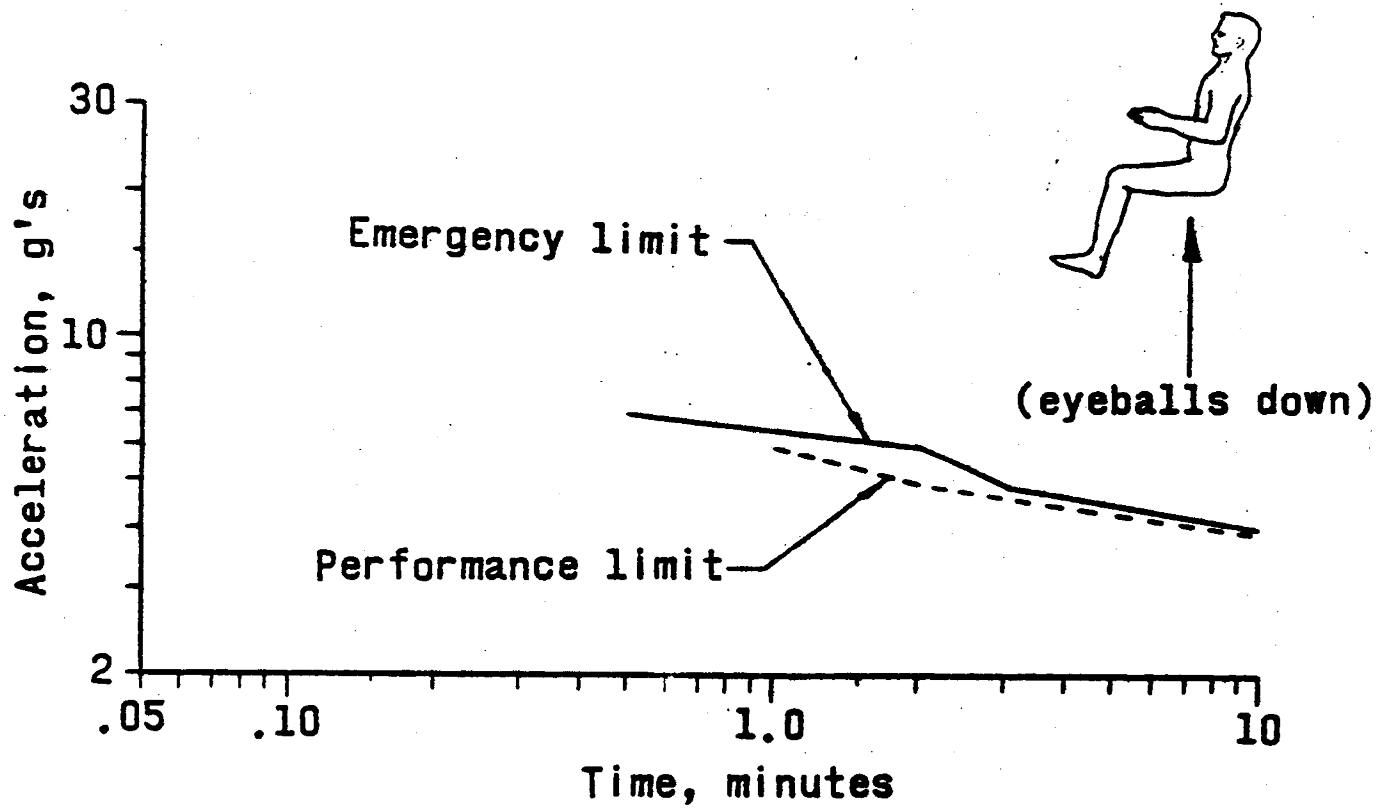

Figure 10.- Sustained acceleration. (References 1, 5 and 6).

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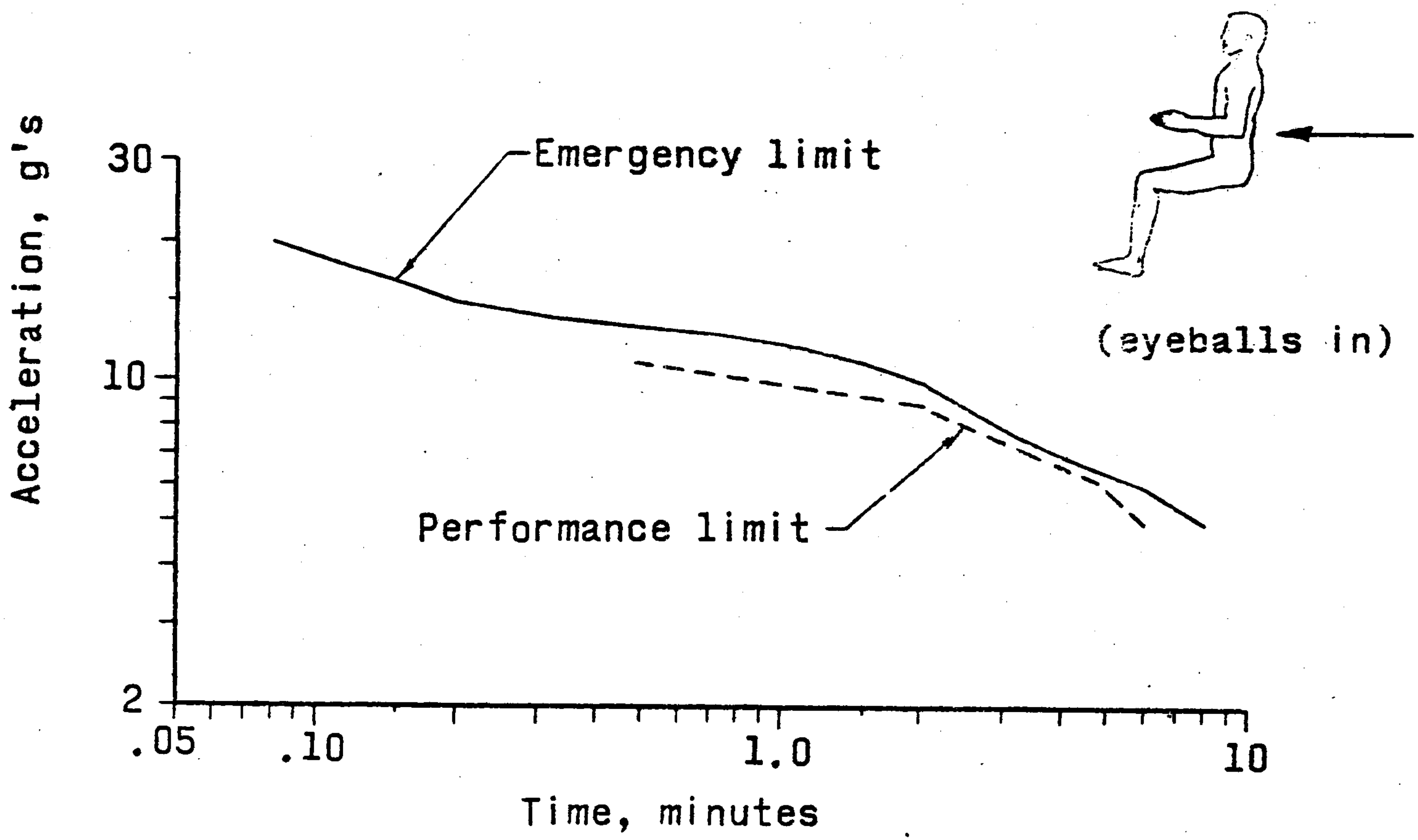

Figure 11.- Sustained acceleration. (References 1 thru 4 and 8).

[redacted]

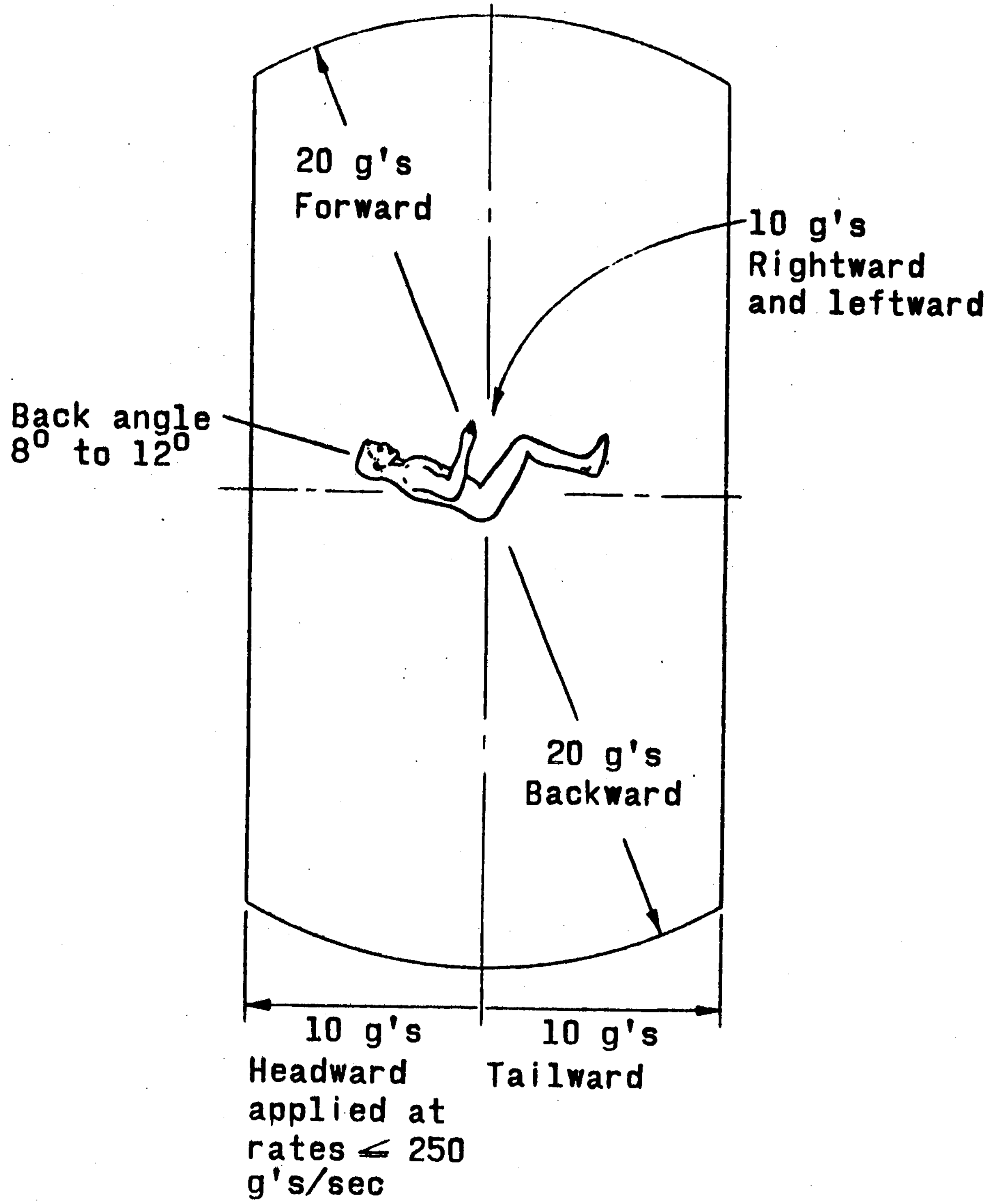

Figure 12.- Impact accelerations - nominal limits.

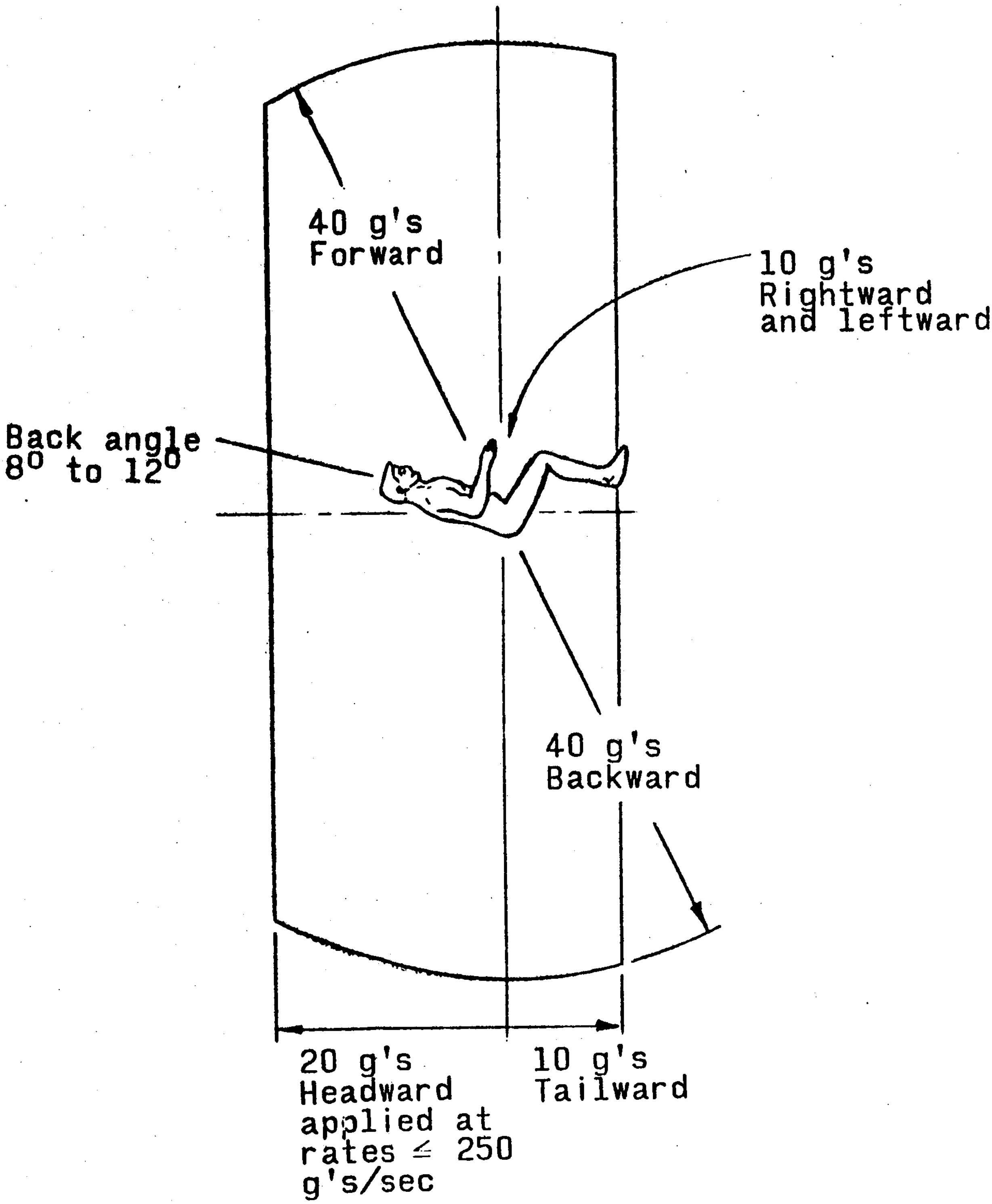

Figure 13.- Impact accelerations - emergency limits.

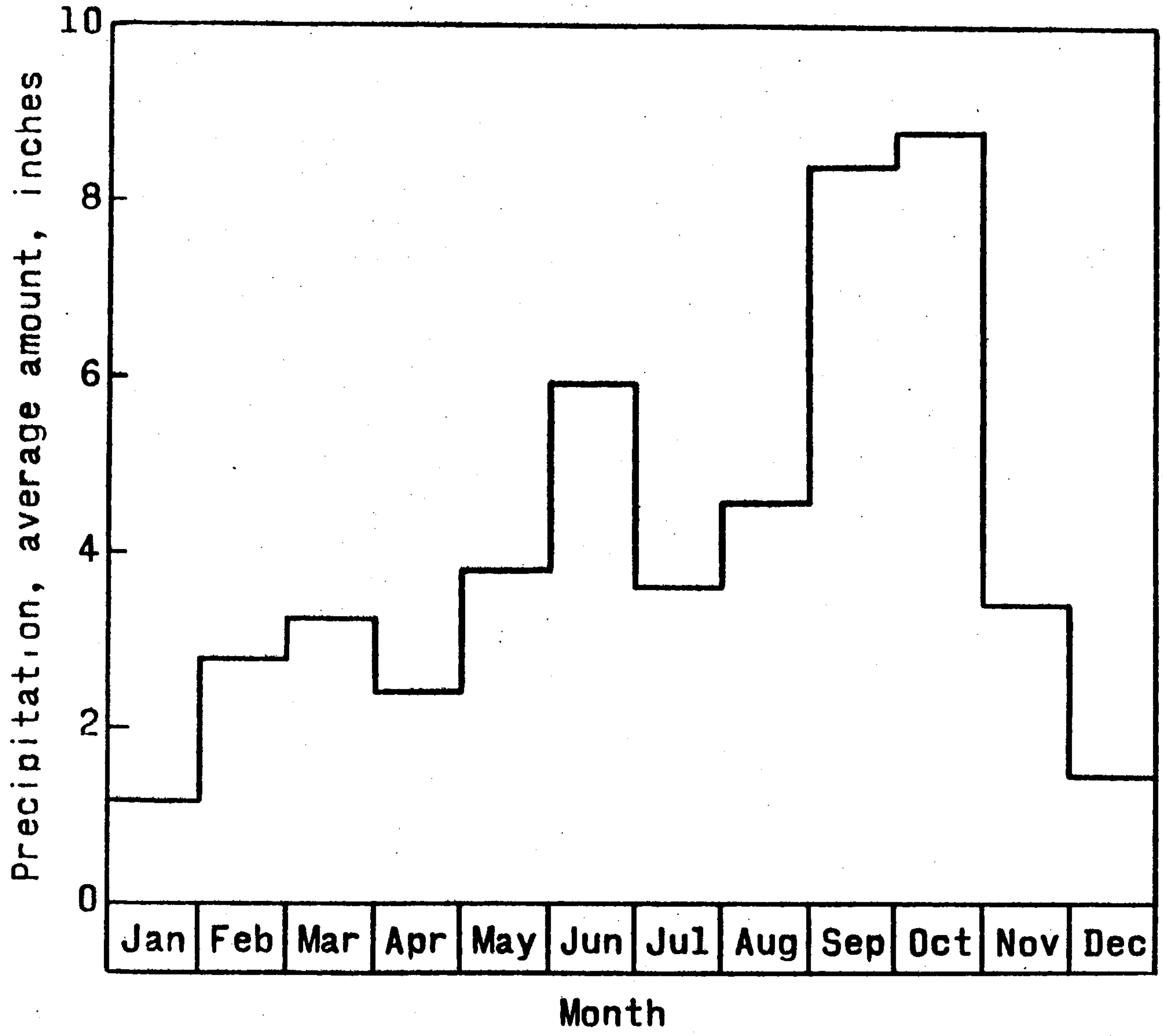

Figure 14.- Average monthly preceiptation, Patrick Air Force Base, Florida.

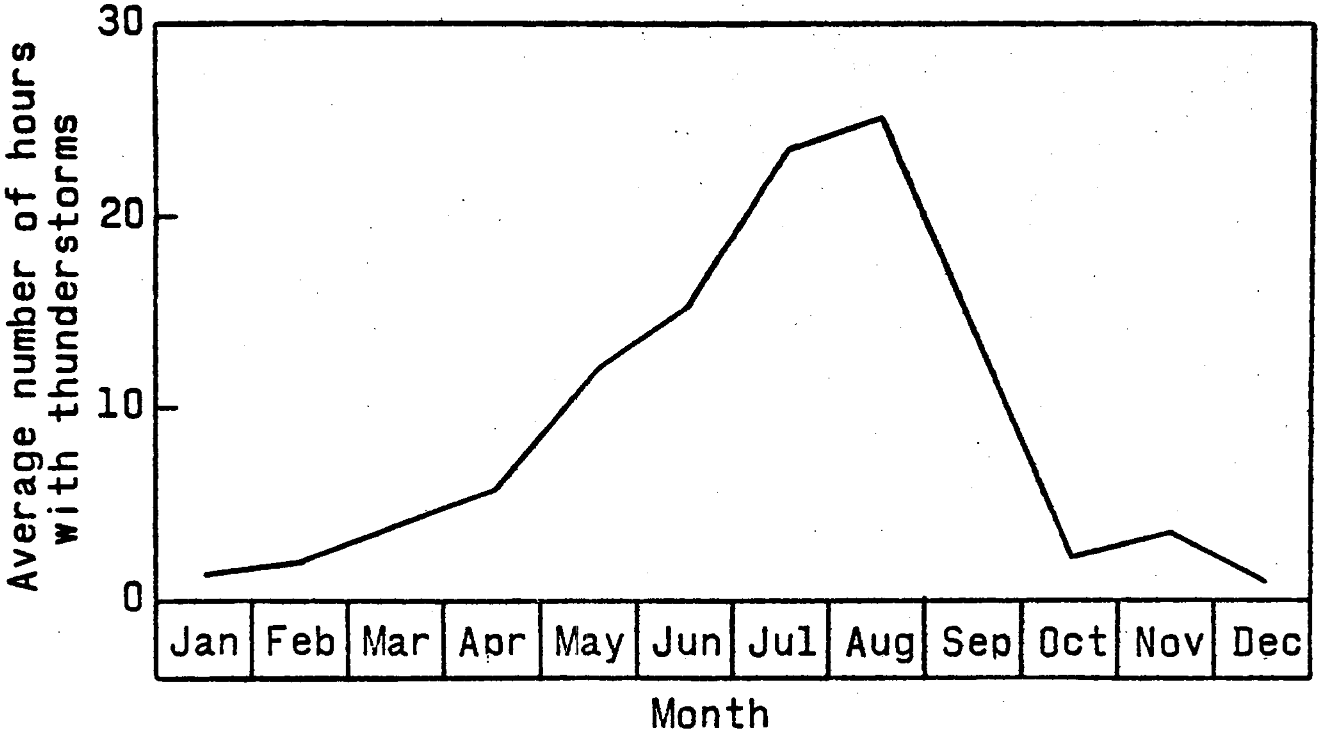

Figure 15.- Average number of hours with thunderstorms, Patrick Air Force Base, Florida.

[redacted]

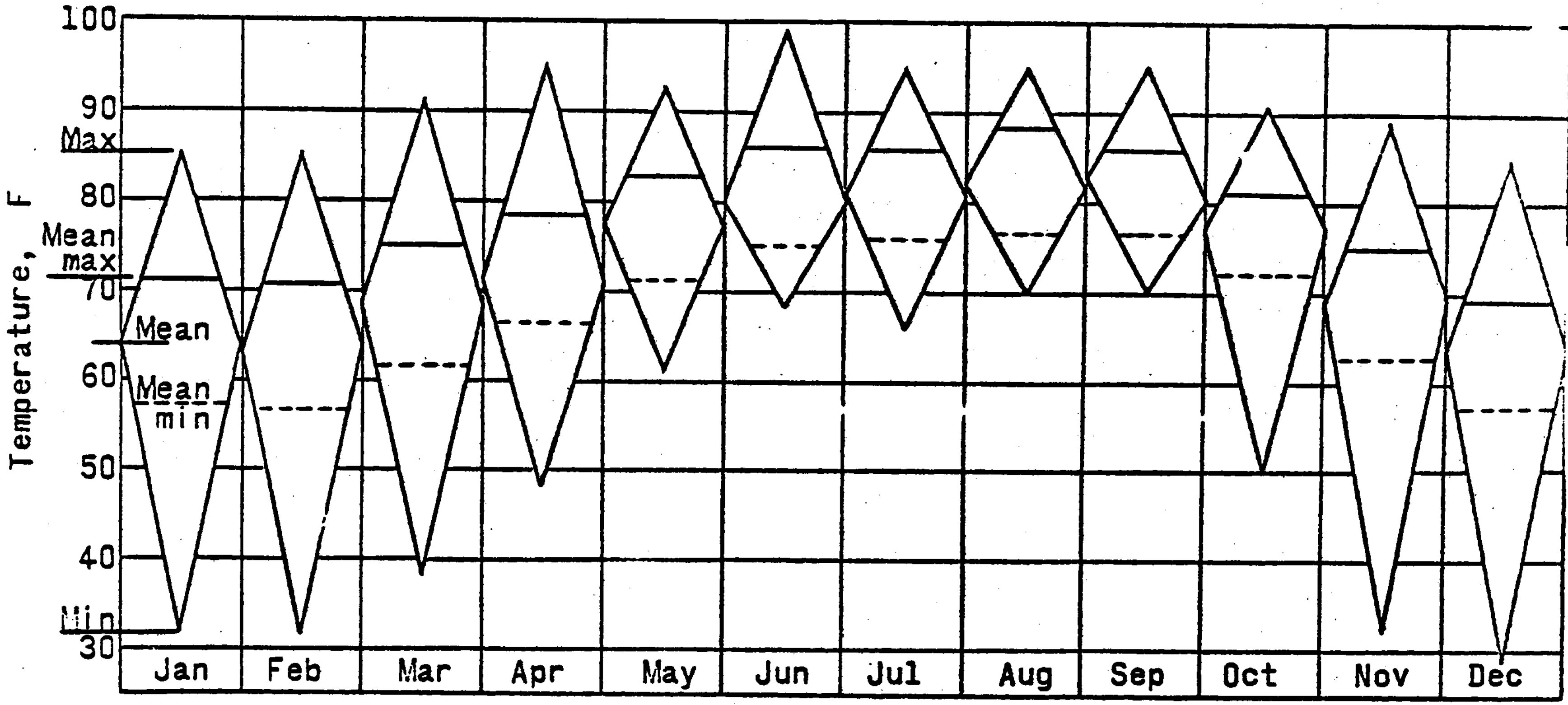

Figure 16.- Monthly temperature variations at Patrick Air Force Base, Florida.

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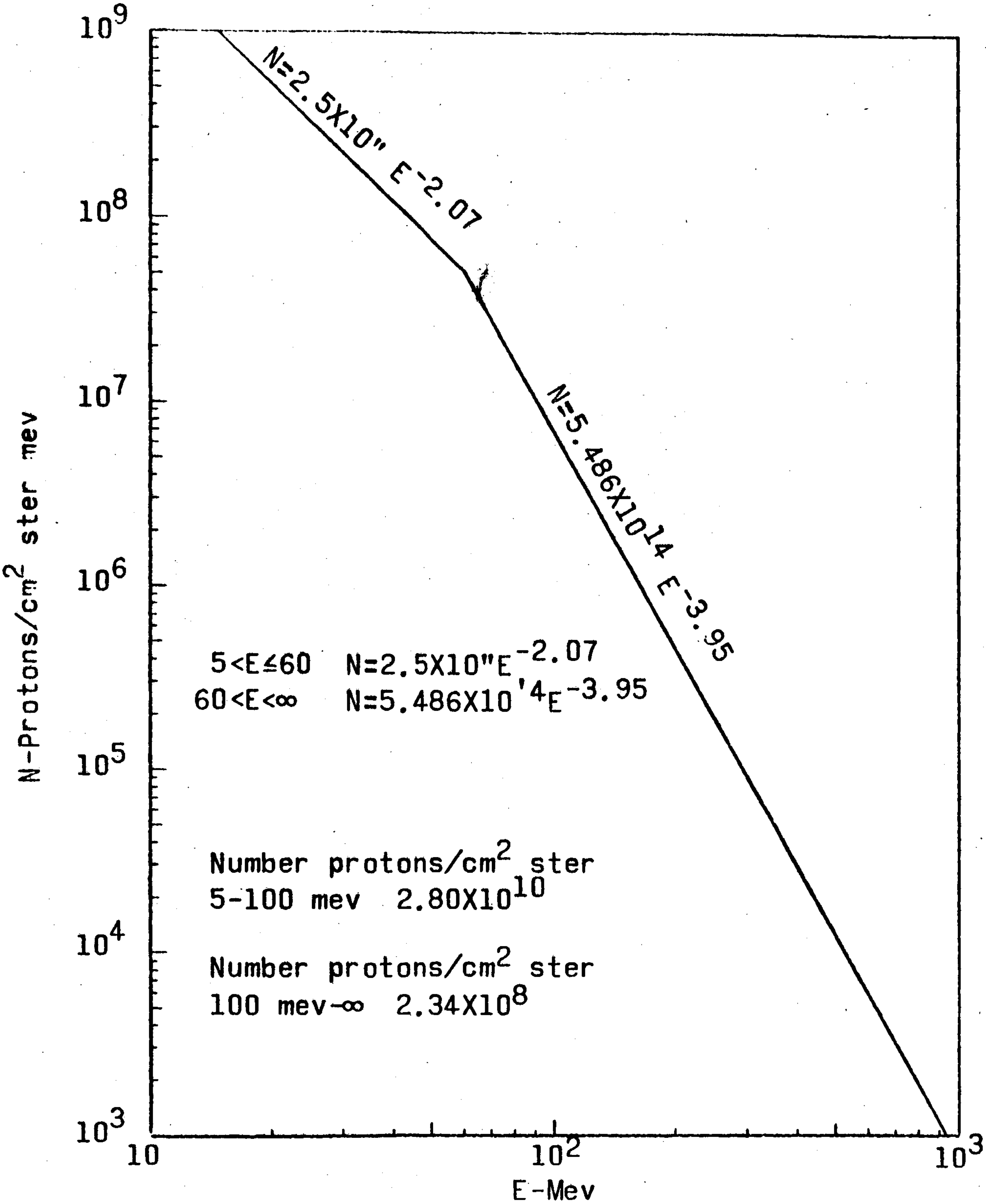

Figure 17.- Time integrated differential energy spectrum for May 10, 1959 event.

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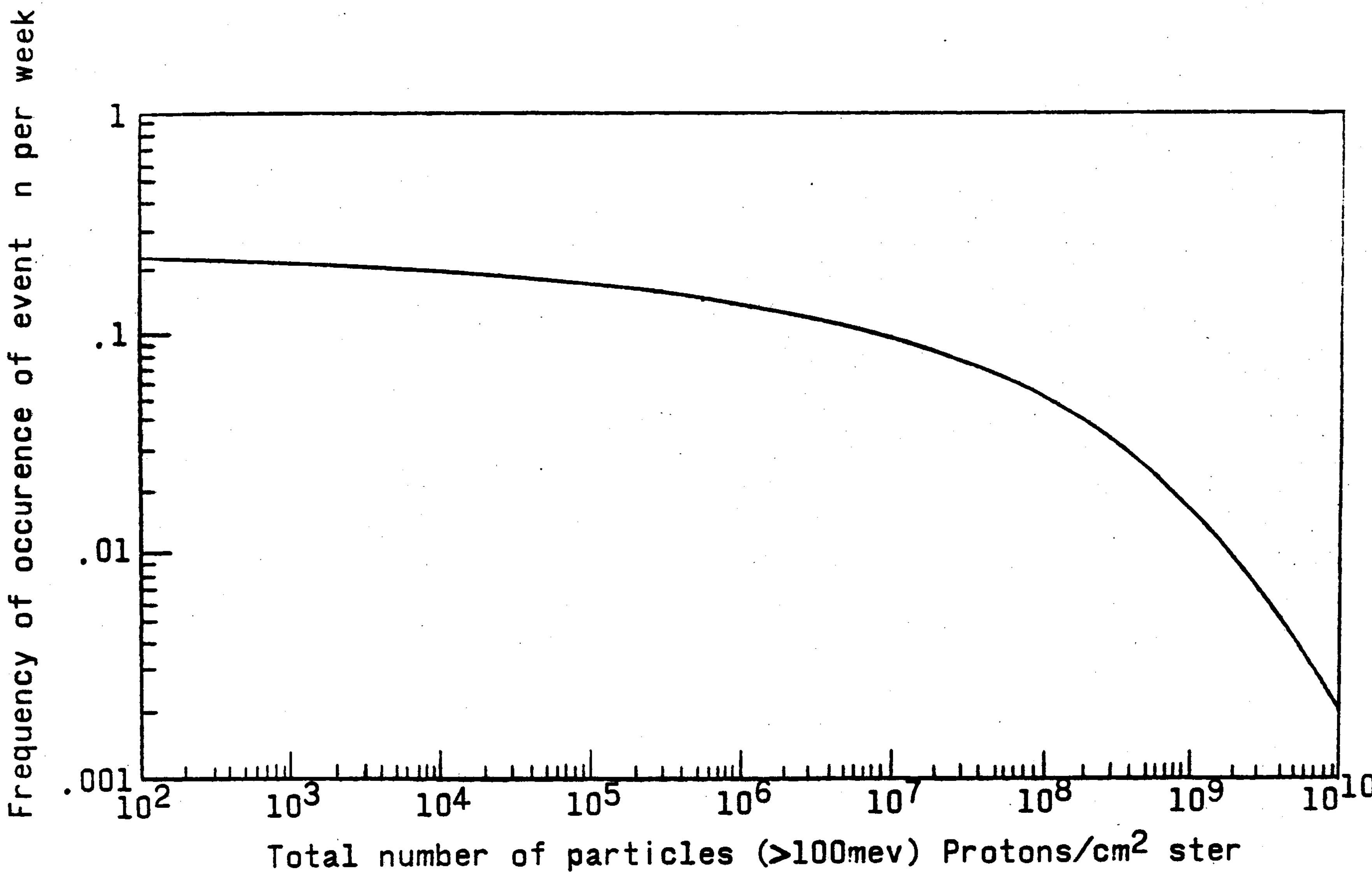

Figure 18.- Frequency distribution of solar proton events.

[redacted]

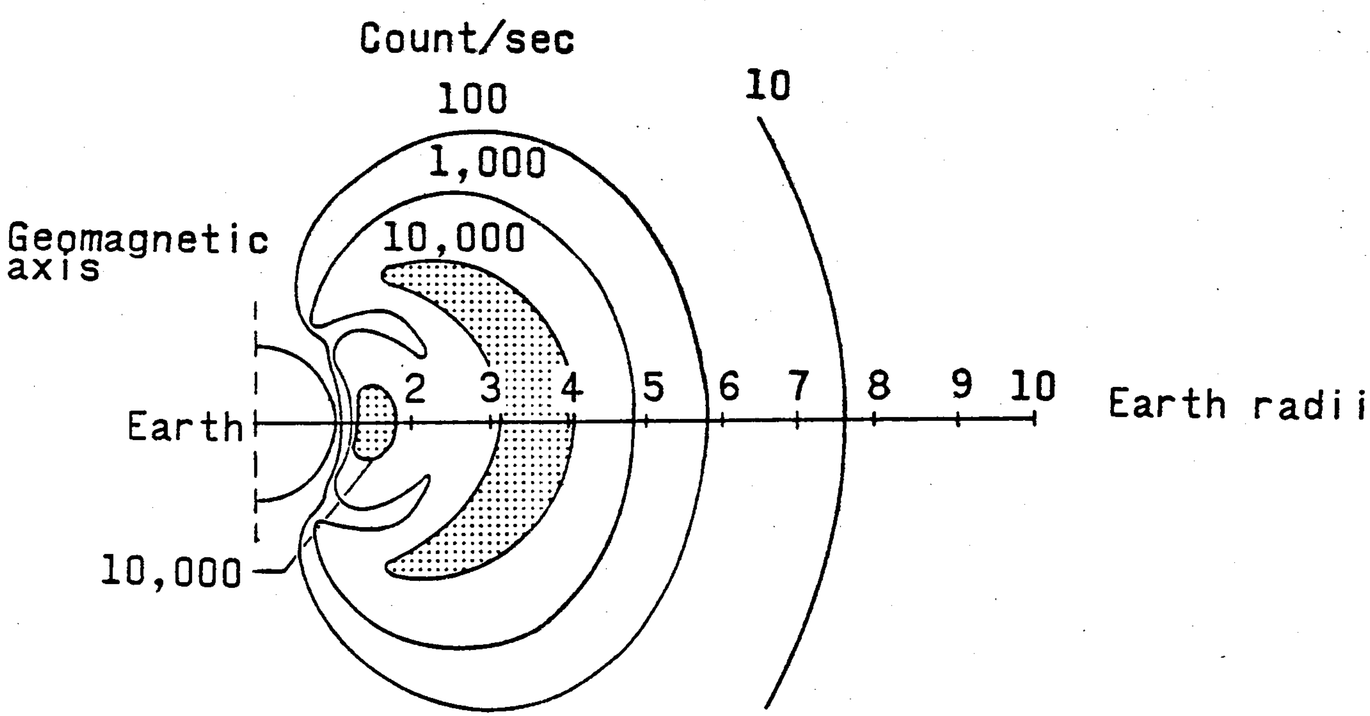

Figure 19.- Model of Van Allen radiation belts.

[redacted]

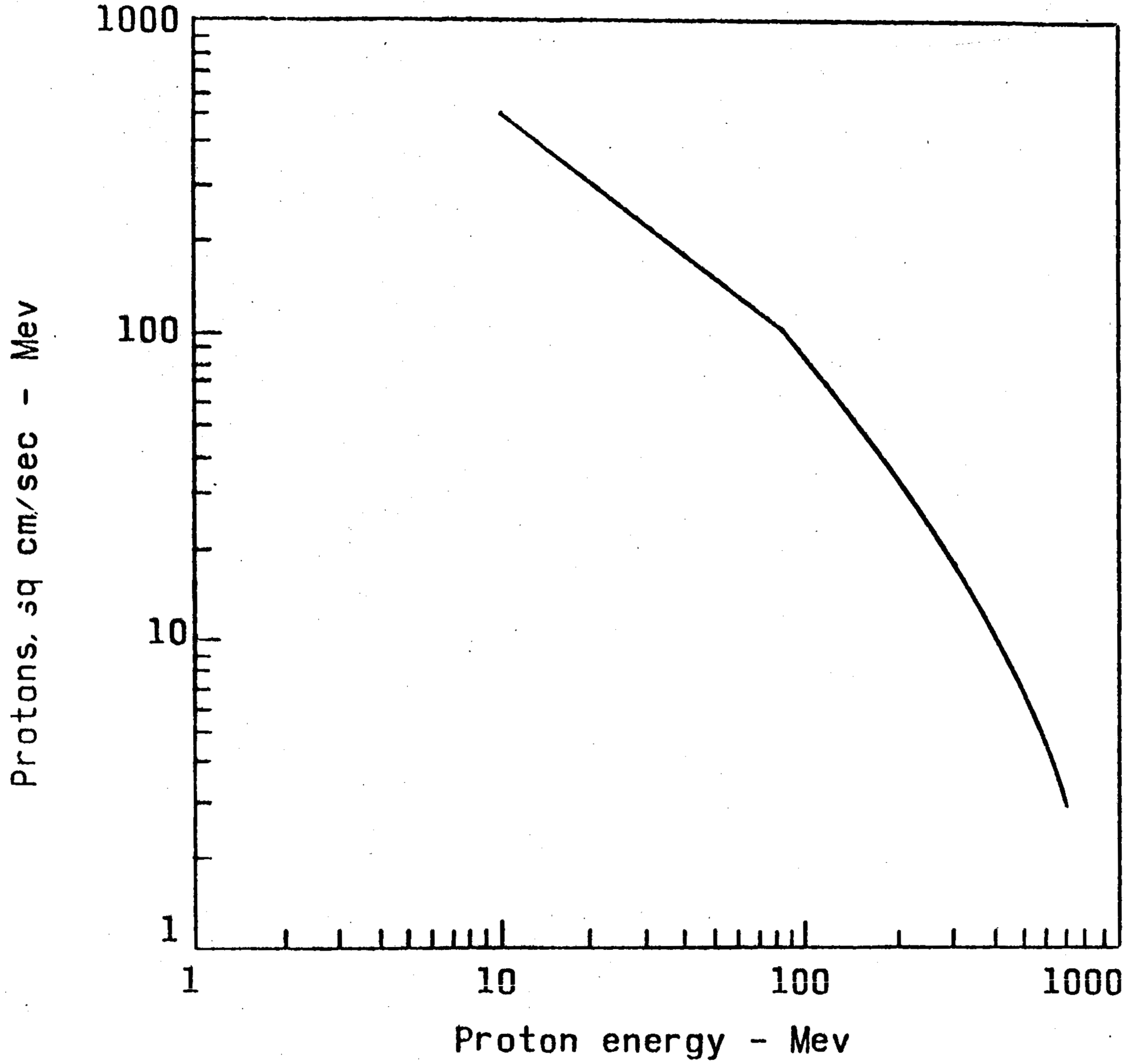

Figure 20.- Integral proton spectrum for the inner Van Allen belt at the geomagnetic equator.

Particles	Energy MEV	Particles/cm^2/sec
Electrons	>.04	10^8
Electrons	>2.4	10^5
Electrons	>5.0	10^2
Protons	>60	10^2
Protons	<30	No information

Figure 21.- Distribution of particles in the heart of the outer Van Allen belt.

[redacted]

WHIPPLE'S DISTRIBUTION FOR SPORADIC METEOROIDS (1961)

Visual Magnit.	Mass Slugs	Mass Grams	Diameter* Microns	Diameter* Inches	Daily Accretion of Earth	Velocity KM/Sec.	Velocity Ft/Sec.
0	1.71×10^{-4}	2.5	11,070	.435	3.3×10^{5}	28	91,900
1	6.82×10^{-5}	9.95×10^{-1}	8,160	.320	1.225×10^{6}	28	91,900
2	2.71×10^{-5}	3.96×10^{-1}	6,000	.236	4.55×10^{6}	28	91,900
3	1.08×10^{-5}	1.58×10^{-1}	4,410	.173	1.69×10^{7}	28	91,900
4	4.30×10^{-6}	6.28×10^{-2}	3,250	.127	6.27×10^{7}	28	91,900
5	1.71×10^{-6}	2.50×10^{-2}	2,390	9.36×10^{-2}	2.33×10^{8}	28	91,900
6	6.82×10^{-7}	9.95×10^{-3}	1,760	6.91×10^{-2}	5.84×10^{8}	28	91,900
7	2.71×10^{-7}	3.96×10^{-3}	1,290	5.07×10^{-2}	1.47×10^{9}	28	91,900
8	1.08×10^{-7}	1.58×10^{-3}	951	3.74×10^{-2}	3.69×10^{9}	27	88,600
9	4.30×10^{-8}	6.28×10^{-4}	700	2.75×10^{-2}	9.26×10^{9}	26	85,300
10	1.71×10^{-8}	2.50×10^{-4}	514	2.02×10^{-2}	2.33×10^{10}	25	82,000
11	6.82×10^{-9}	9.95×10^{-5}	379	1.49×10^{-2}	5.84×10^{10}	24	78,700
12	2.71×10^{-9}	3.96×10^{-5}	279	1.09×10^{-2}	1.47×10^{11}	23	75,500
13	1.08×10^{-9}	1.58×10^{-5}	205	8.04×10^{-3}	3.69×10^{11}	22	72,200
14	4.30×10^{-10}	6.28×10^{-6}	151	5.93×10^{-3}	9.26×10^{11}	21	68,900
15	1.71×10^{-10}	2.50×10^{-6}	111	4.35×10^{-3}	2.33×10^{12}	20	65,600
16	6.82×10^{-11}	9.95×10^{-7}	81.6	3.20×10^{-3}	5.84×10^{12}	19	62,300
17	2.71×10^{-11}	3.96×10^{-7}	60	2.36×10^{-3}	1.47×10^{13}	18	59,100
18	1.08×10^{-11}	1.58×10^{-7}	44.1	1.73×10^{-3}	3.69×10^{13}	17	55,800
19	4.30×10^{-12}	6.28×10^{-8}	32.5	1.27×10^{-3}	9.26×10^{13}	16	52,500
20	1.71×10^{-12}	2.50×10^{-8}	23.9	9.36×10^{-4}	2.33×10^{14}	15	49,200
21	6.82×10^{-13}	9.95×10^{-9}	17.6	6.91×10^{-4}	5.84×10^{14}	15	49,200
22	2.71×10^{-13}	3.96×10^{-9}	12.9	5.07×10^{-4}	1.47×10^{15}	15	49,200
23	1.08×10^{-13}	1.58×10^{-9}	9.5	3.74×10^{-4}	3.69×10^{15}	15	49,200
24	4.30×10^{-14}	6.28×10^{-10}	7.00	2.75×10^{-4}	9.26×10^{15}	15	49,200
25	1.71×10^{-14}	2.50×10^{-10}	5.14	2.02×10^{-4}	2.33×10^{16}	15	49,200

* Diameters based on ρ_m = 3.5 grams/cc.

FIGURE 23. - Whipple's distribution for sporadic meteoroids.

[redacted]

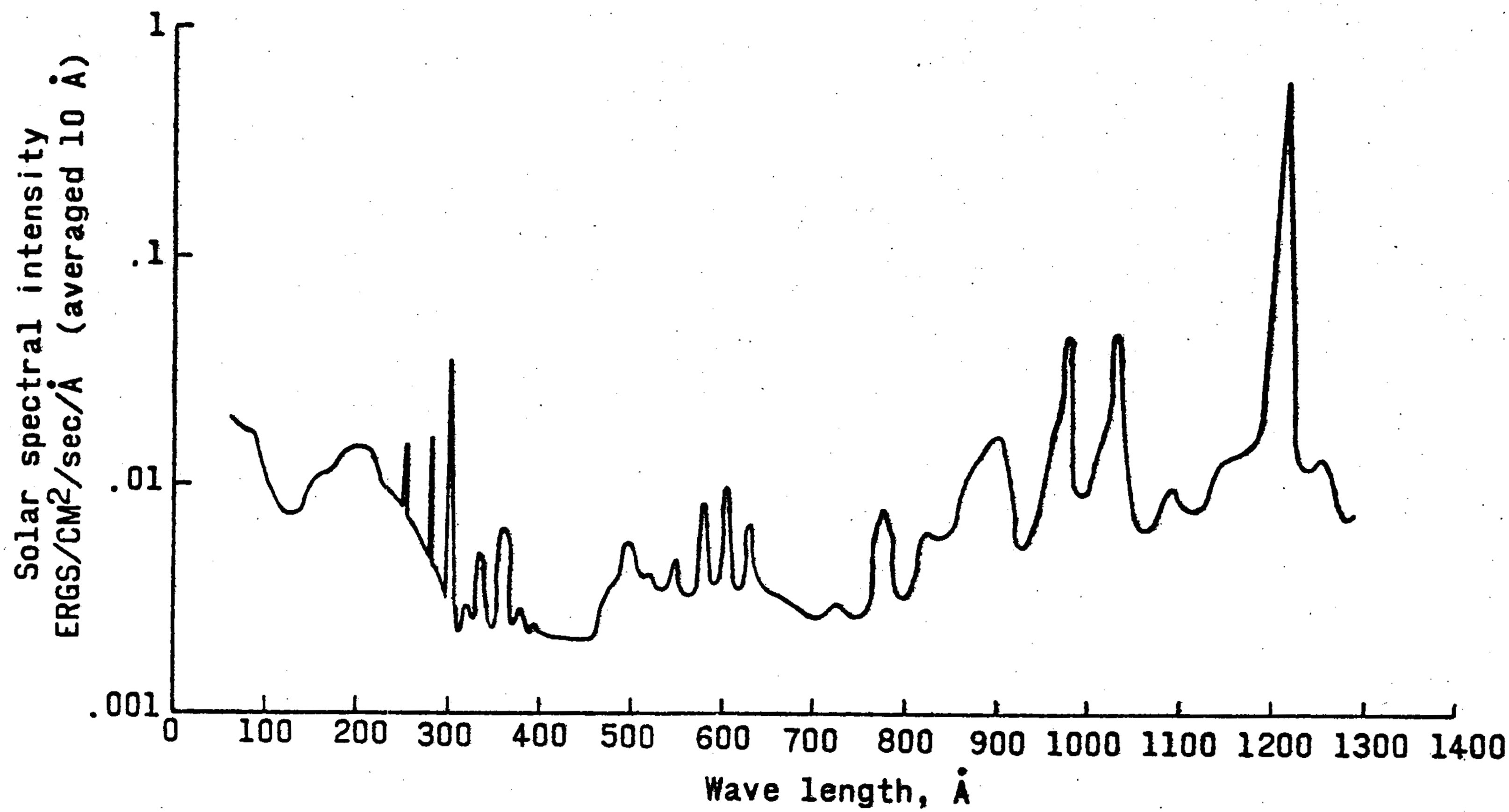

Figure 24.- Electromagnetic spectrum for solar radiation.

[redacted]

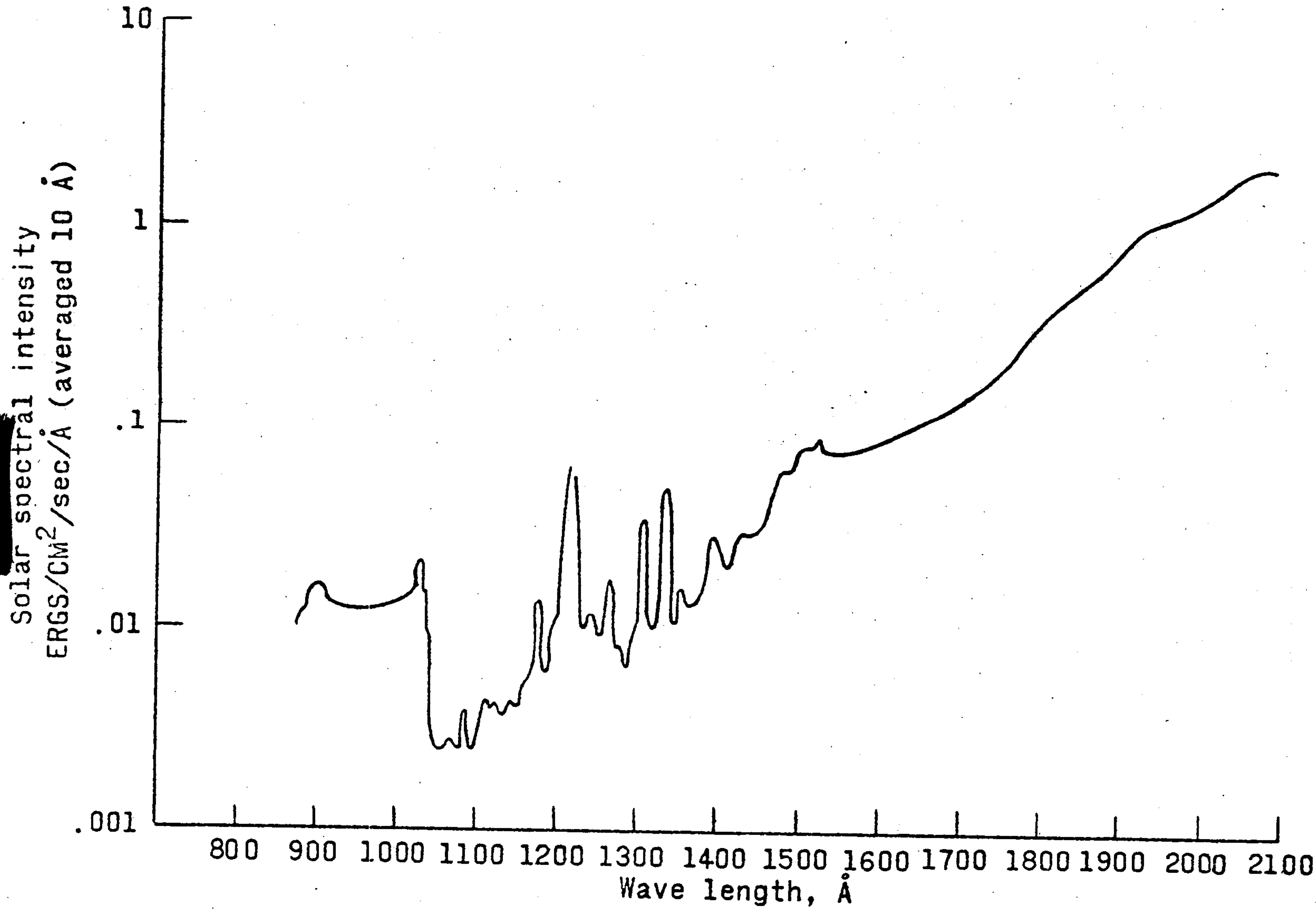

Figure 25.- Electromagnetic spectrum for solar radiation.

[redacted]

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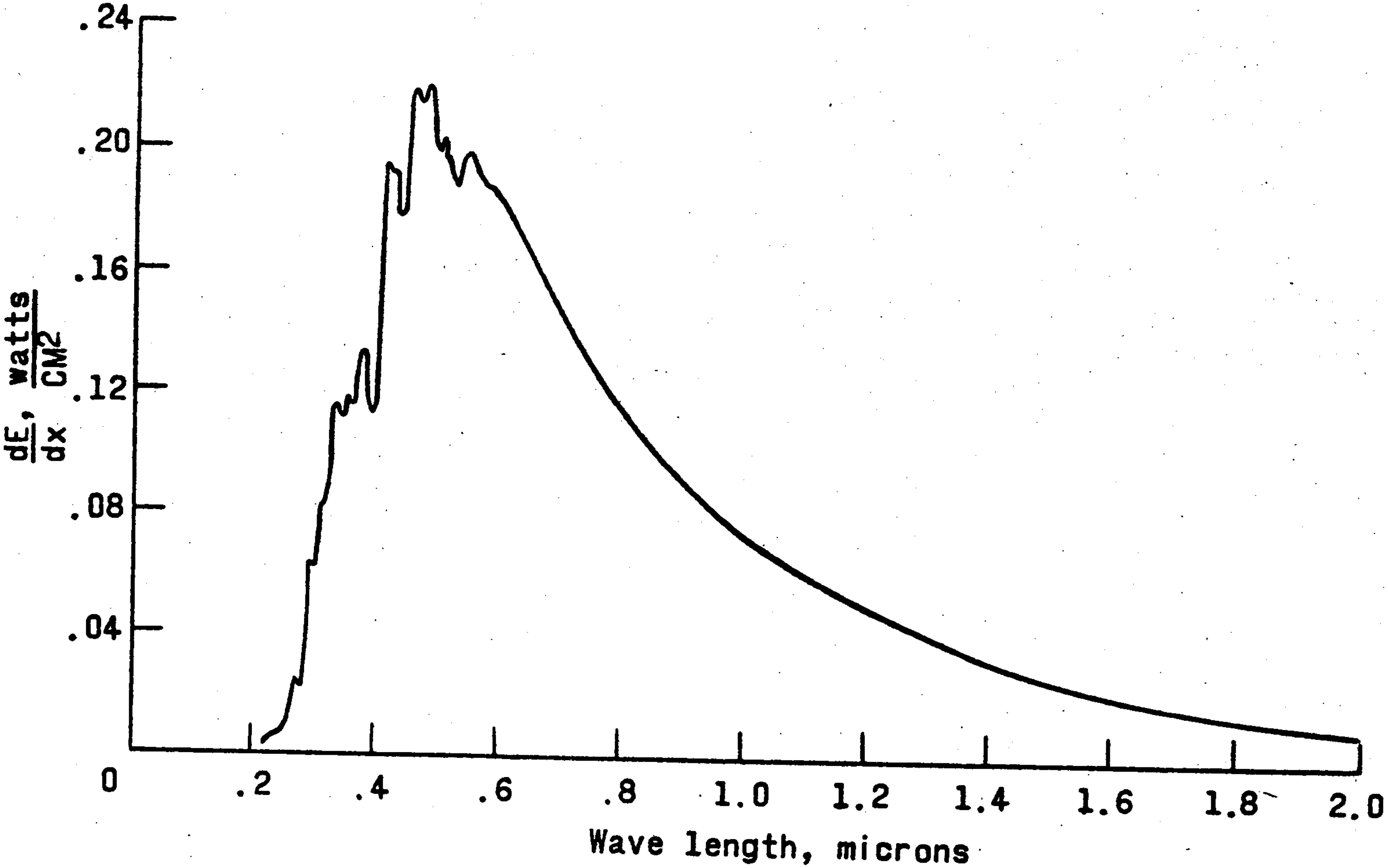

Figure 26.- Electromagnetic spectrum for solar radiation.

[redacted]

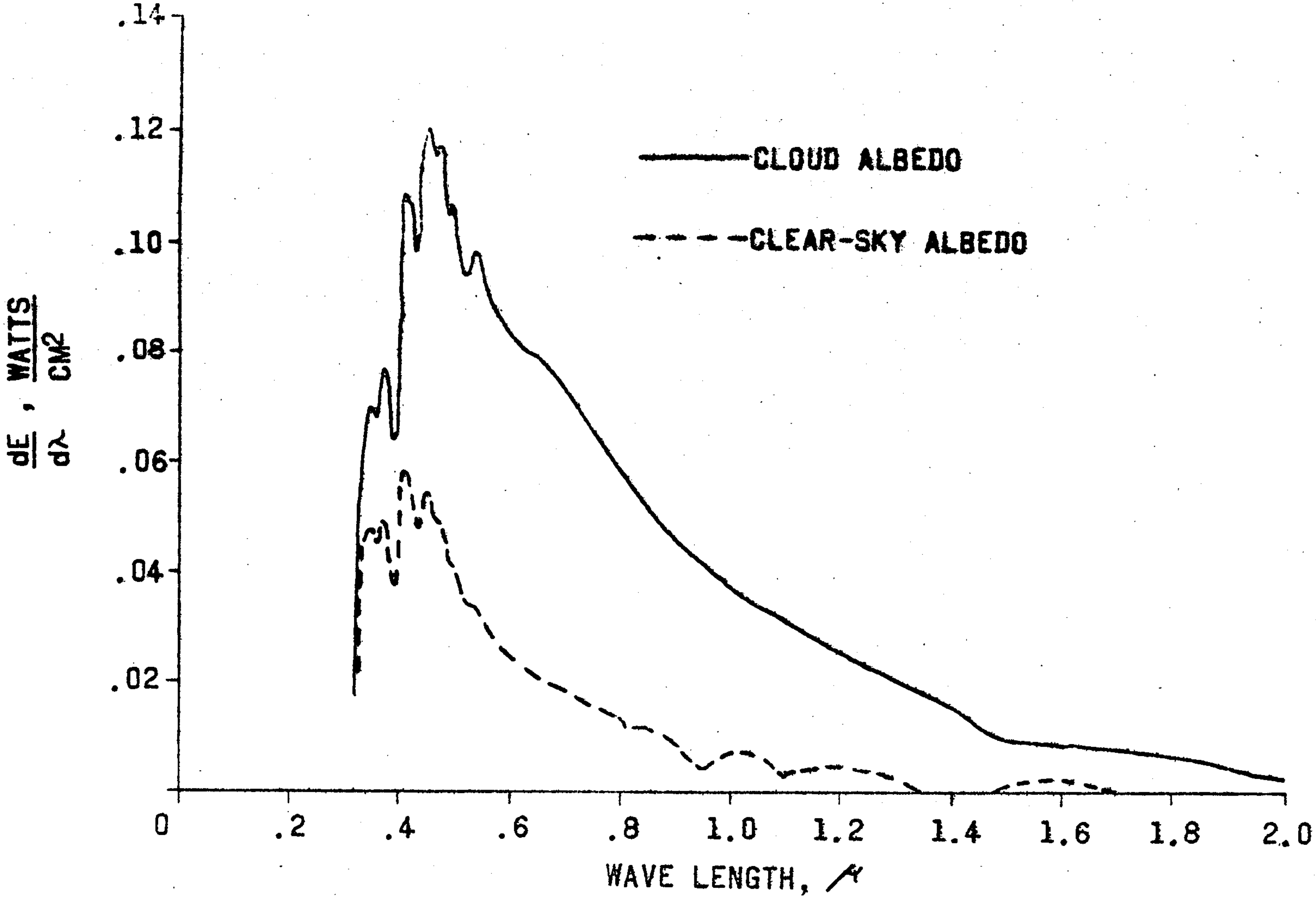

Figure 27.- Spectrum of the Earth's albedo.

[redacted]

Equivalent pressure	Equivalent density	Composition
10^{-6} dynes/cm^2	10^{-16} grams/cm^3	Hydrogen atoms

Figure 30.- Interplanetary atmosphere.

[redacted]

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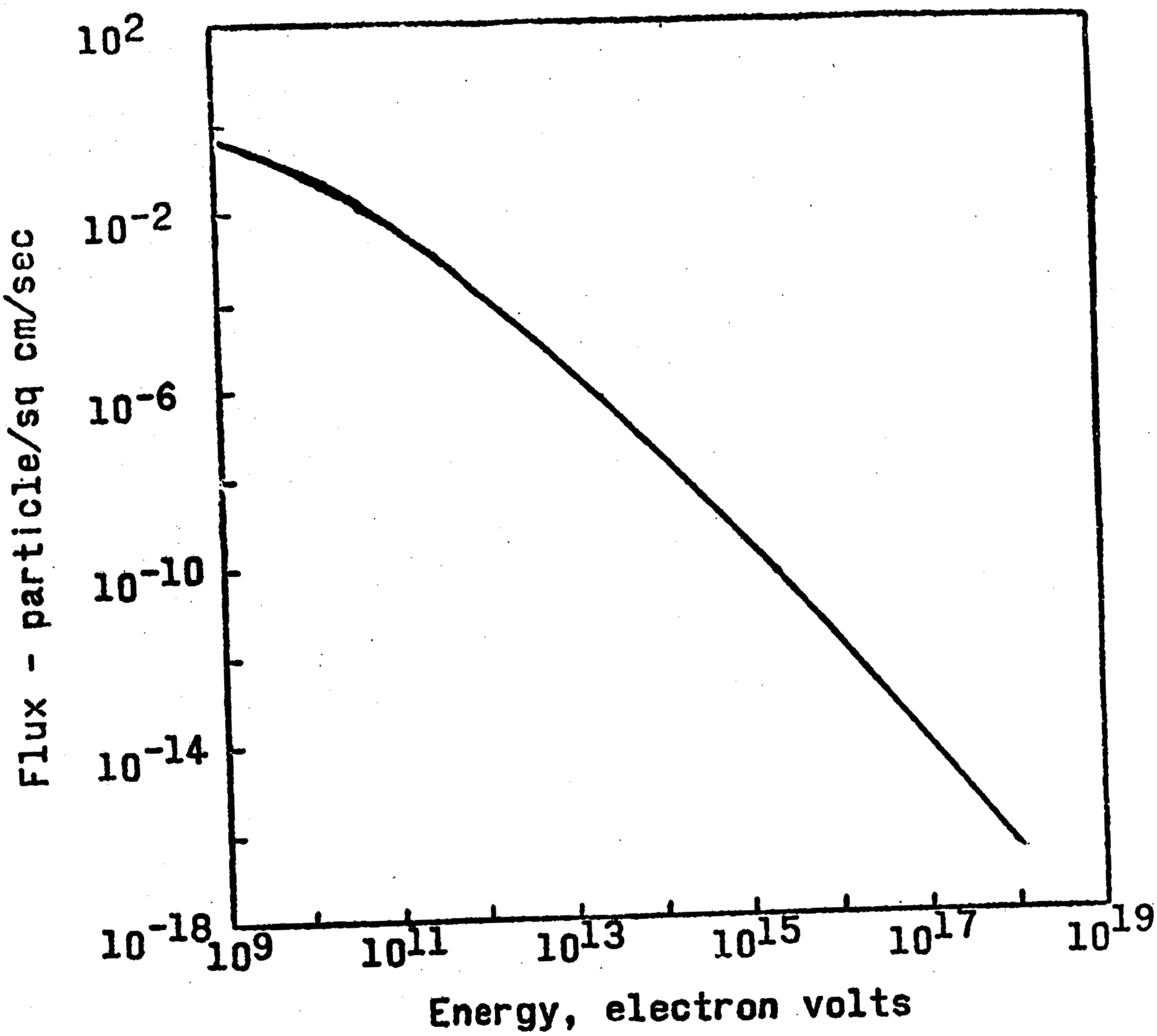


Figure 31.- Galactic cosmic ray flux.

[redacted]

[redacted]

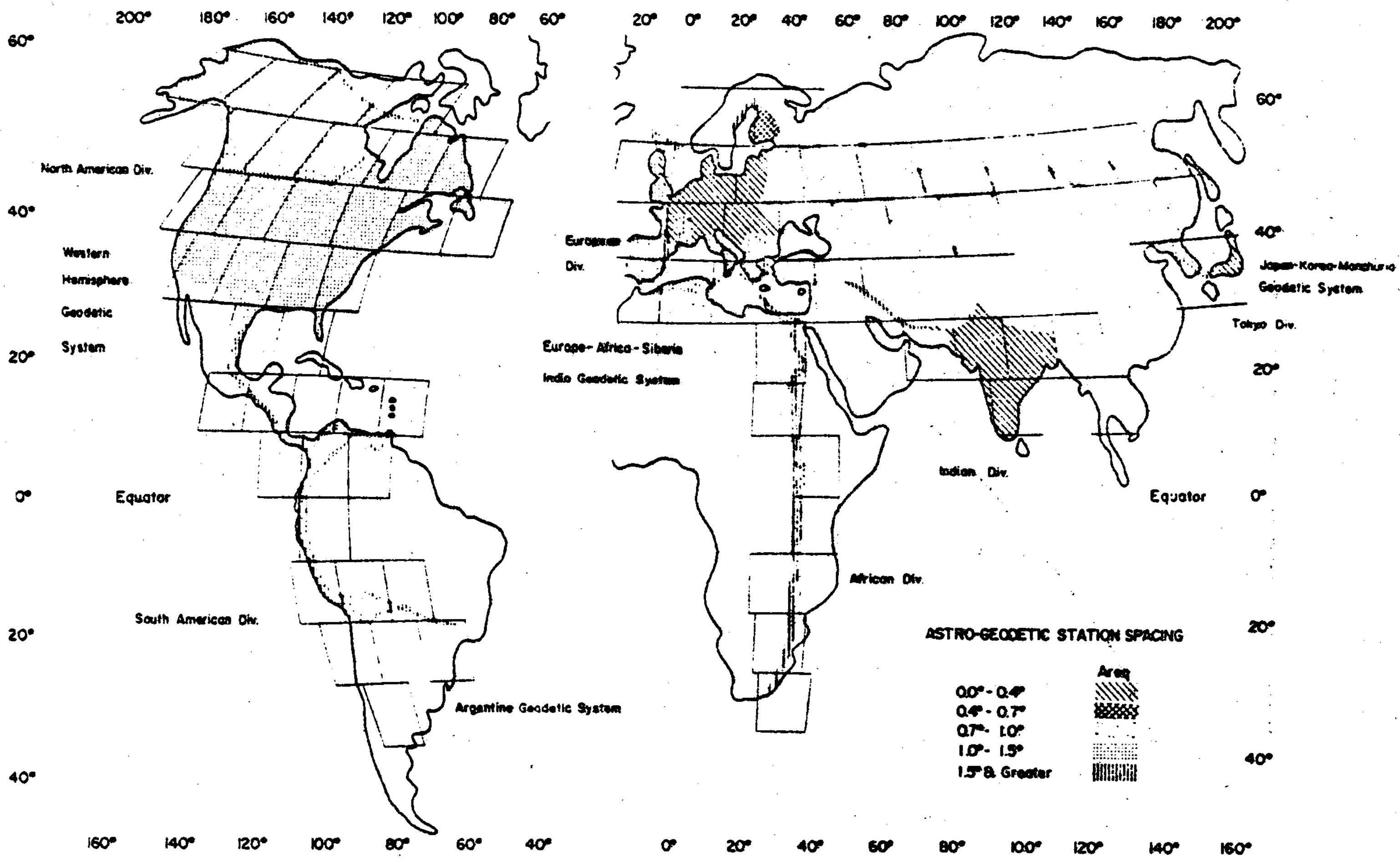


Figure 32.- Astro-geodetic geoid data station spacing and distribution.

[redacted]

[redacted]

Systems	Stations	Correction Δu Meters	Δv Meters	Δw Meters
Western Hemisphere Geodetic System	NAD	-23	+142	+196
	SAD	-303	+98	-315
	SAO SP59	+4	+299	+15
	Vanguard	-12	+235	+120
	σ	±26	±22	±22
Europe-Africa-Siberia-India Geodetic System	ED	-57	-37	-96
	Indian	+200	+782	+271
	Arc	-109	-70	-289
	SAO SP59	-150	-2	-33
	σ	±23	±29	±23
Japan-Korea-Manchuria Geodetic System	Tokyo	-89	+551	+710
	SAO SP59	-29	-209	-147
	σ	±40	±53	±40
Australia Geodetic System	Sidney	+198	+262	-21
	SAO SP59	+149	-83	+116
	σ (Estimated)	±75	±90	±35
Argentina Geodetic System	SAO SP59	-81	+131	+105
	σ (Estimated)	±180	±160	±160

Figure 33.- Geodetic station location correction data. (Reference 11).

[redacted]

[redacted]

Planet	M_s/M_p	ω	f	GM
Sun	1.	3.0050435×10^{-6}	0	$1.32715445 \times 10^{11}$
Mercury	6,120,000.		0	
Venus	406,645.	Synchronous	0	3.247695×10^{5}
Earth	332,488.		1/298.30	3.986032×10^{5}
Mars	3,088,000.	7.0882232×10^{-5}	1/191.8	4.297780×10^{4}
Jupiter	1,047.39	1.7734082×10^{-4}	1/15.2	1.267106×10^{8}
Saturn	3,500.	1.7055335×10^{-4}	1/10.2	
Uranus	22,869.	1.6135556×10^{-4}	1/14.	
Neptune	18,889.	1.1140400×10^{-4}	1/58.5	
Pluto	400,000.			

$$G = (6.668 \pm .0005) \times 10^{-8} \frac{cm^3}{sec^2\,gram}$$

$$M_e = (5.977 \pm .004) \times 10^{27} \text{ grams}$$

$$T = 86164.09054 \text{ seconds}$$

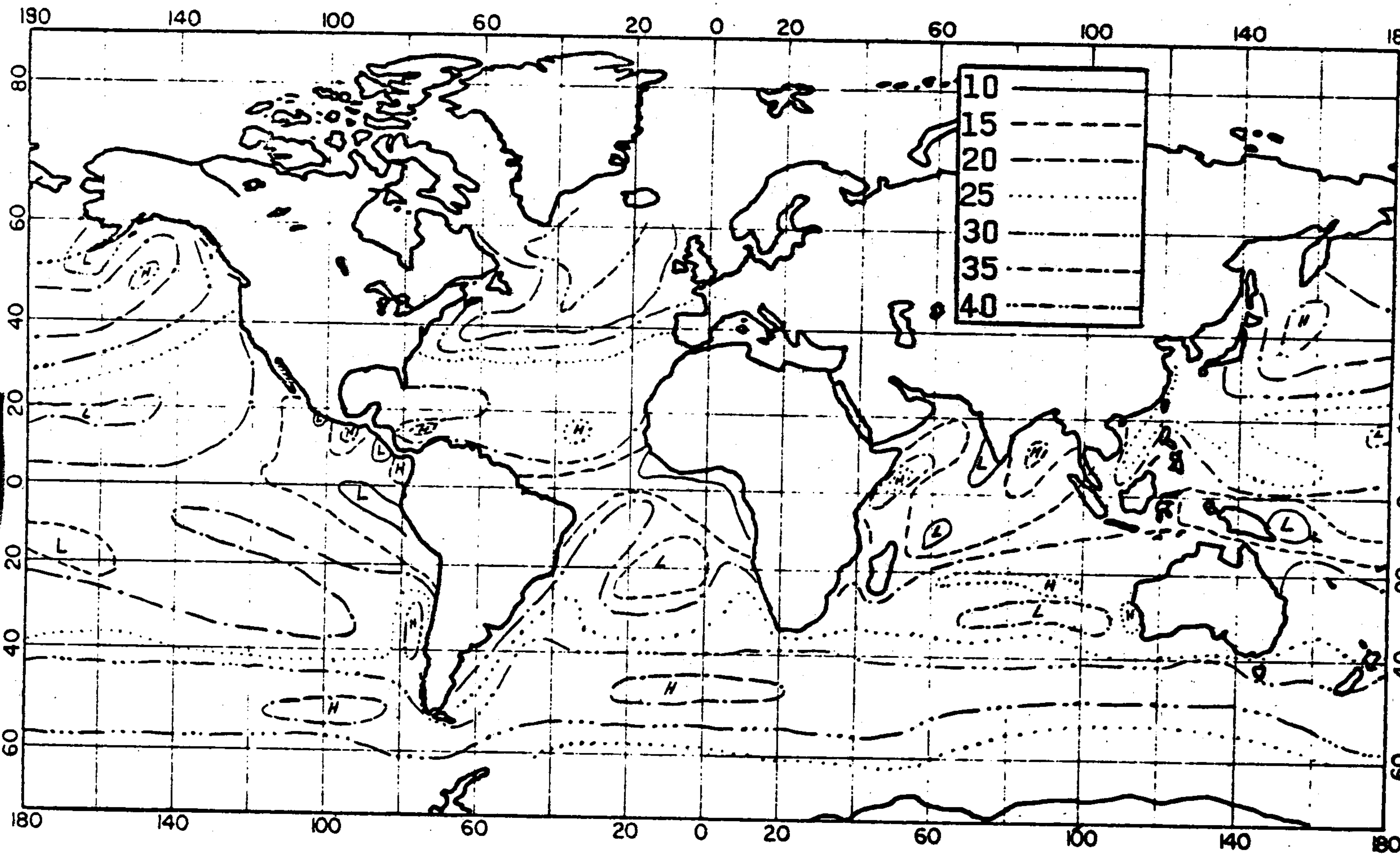
$$A_u = 1.49599 \times 10^{11} \text{ meters}$$

$$\frac{M_e}{M_m} = 81.375$$

Figure 34.- Sun, moon, and planetary constants.

[redacted]

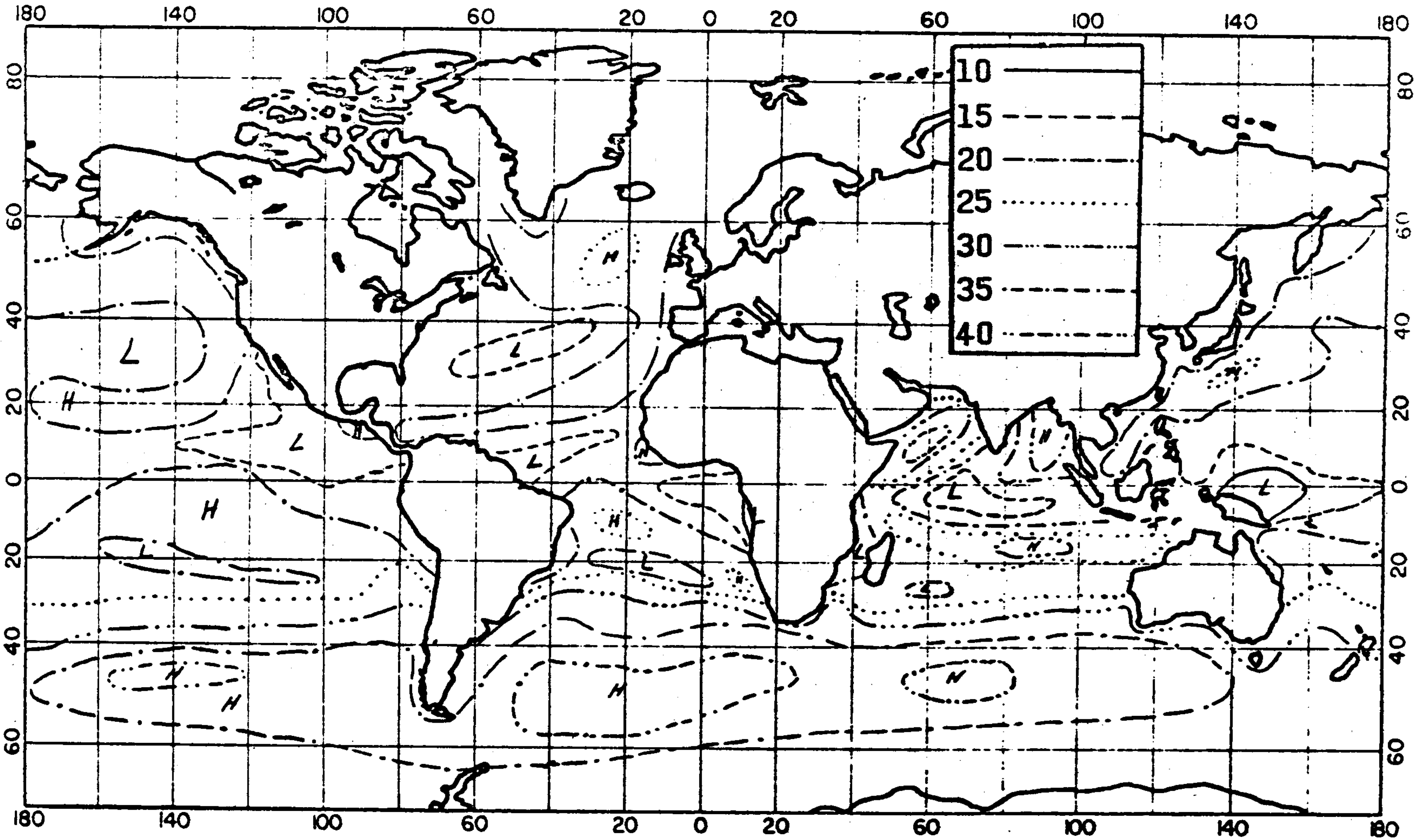
[redacted]



(a) January.

Figure 35.- Wind speed (knots) exceeded 10 percent of the time.

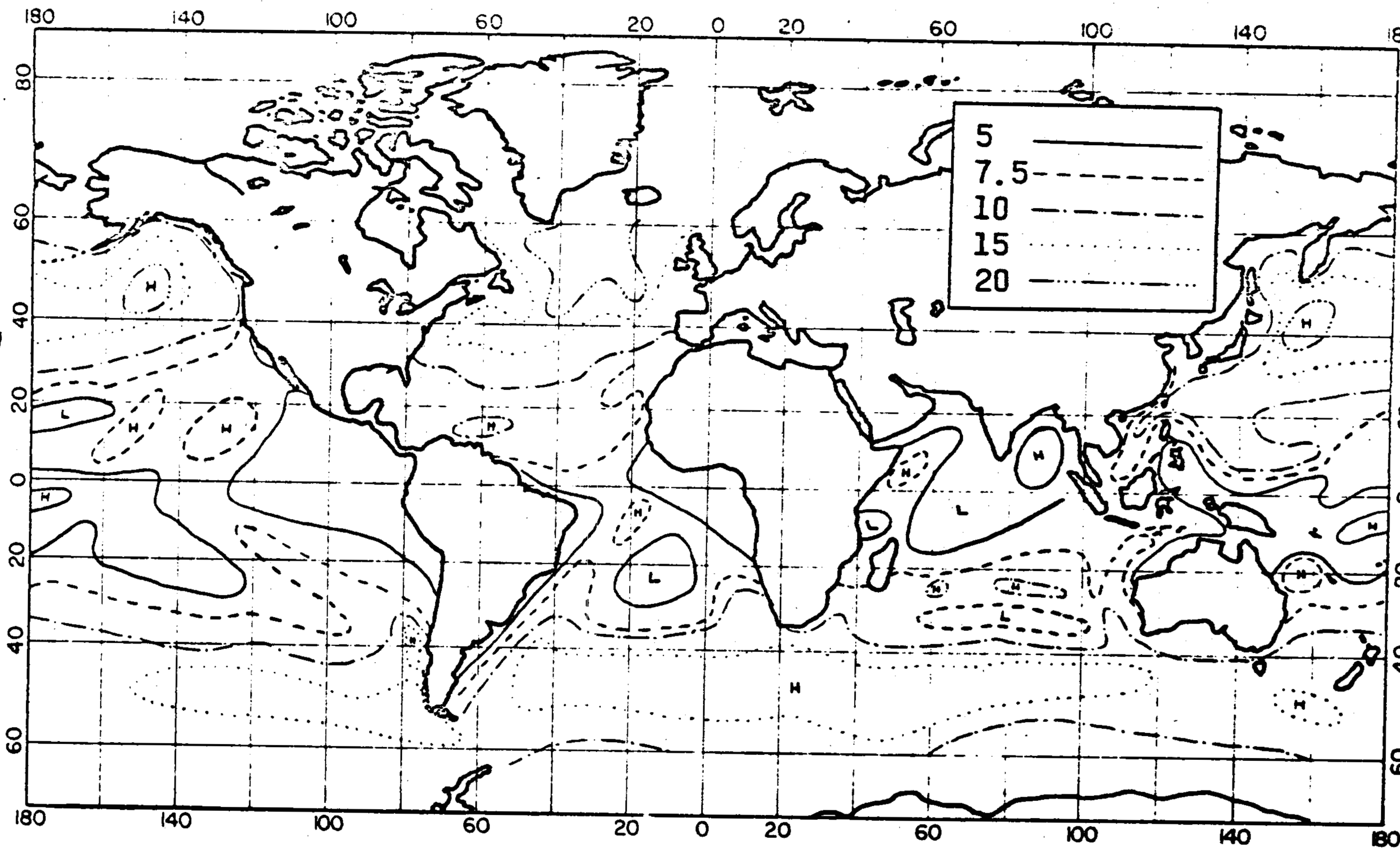
[redacted]



(b) July.

Figure 35.- Concluded.

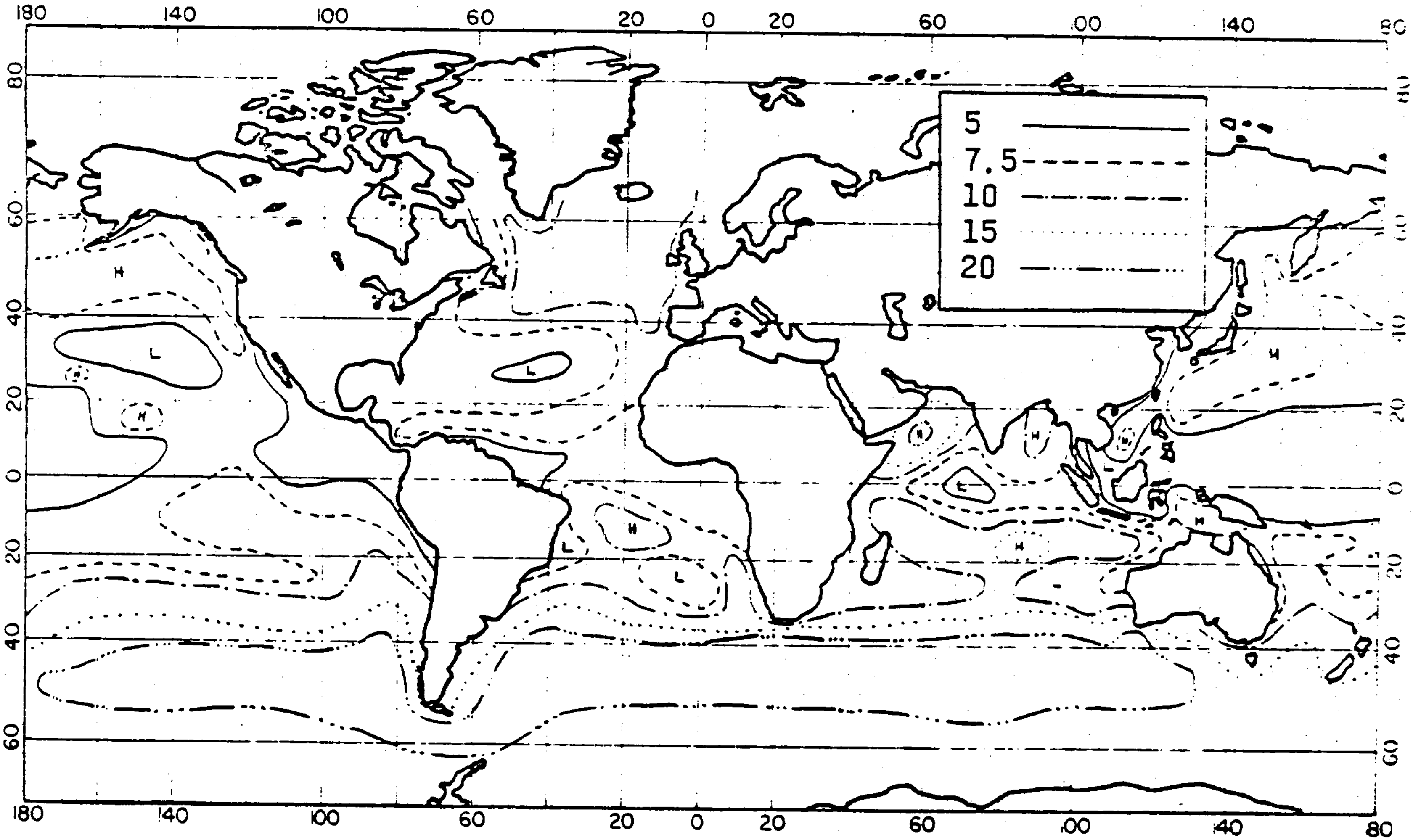
[redacted]



(a) January.

Figure 36.- Wave height (feet) exceeded 10 percent of the time.

[redacted]



(b) July.

Figure 36.- Concluded.

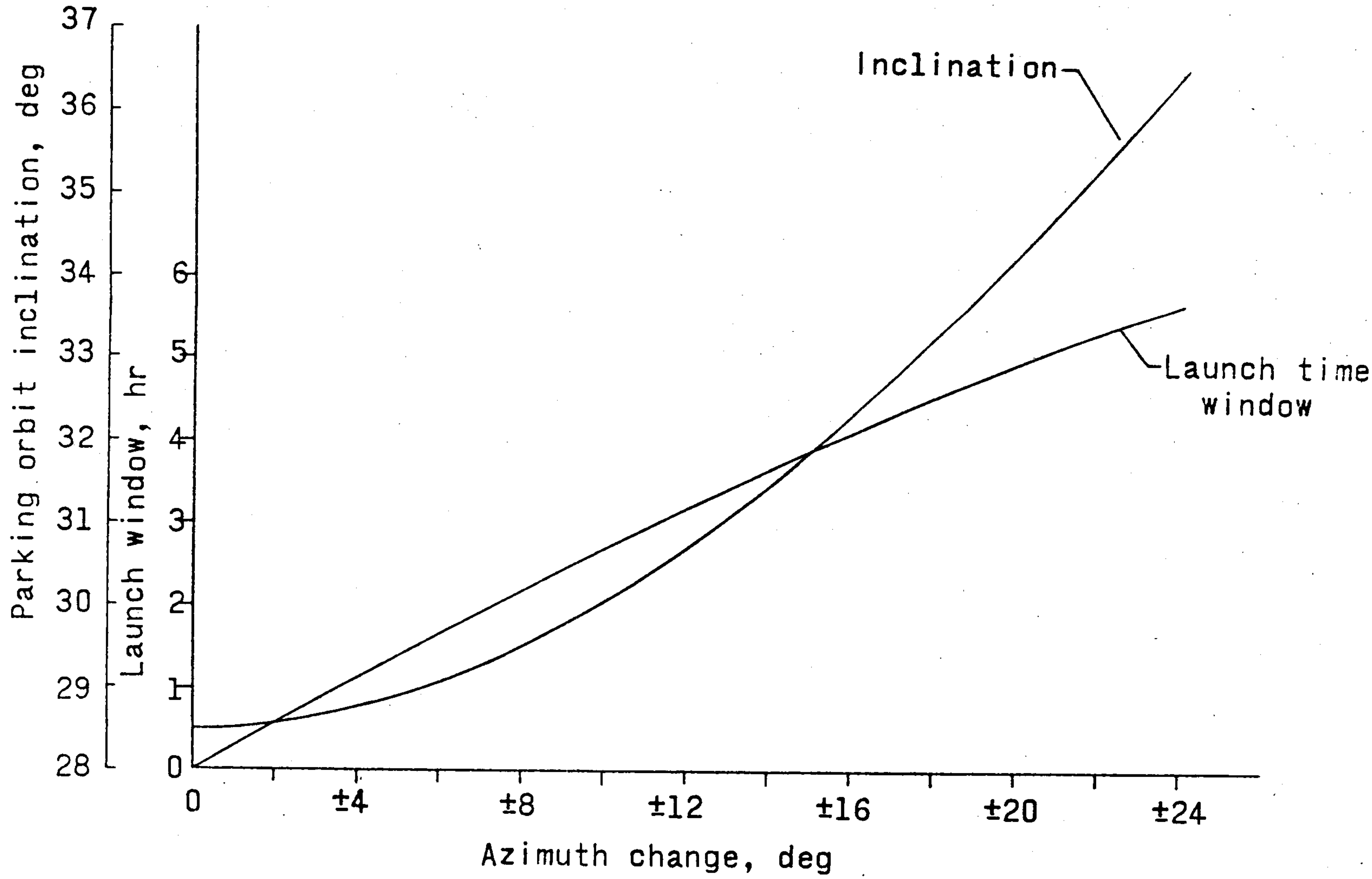


Figure 37.- Launch time window for variation in the translunar trajectory.

[redacted]

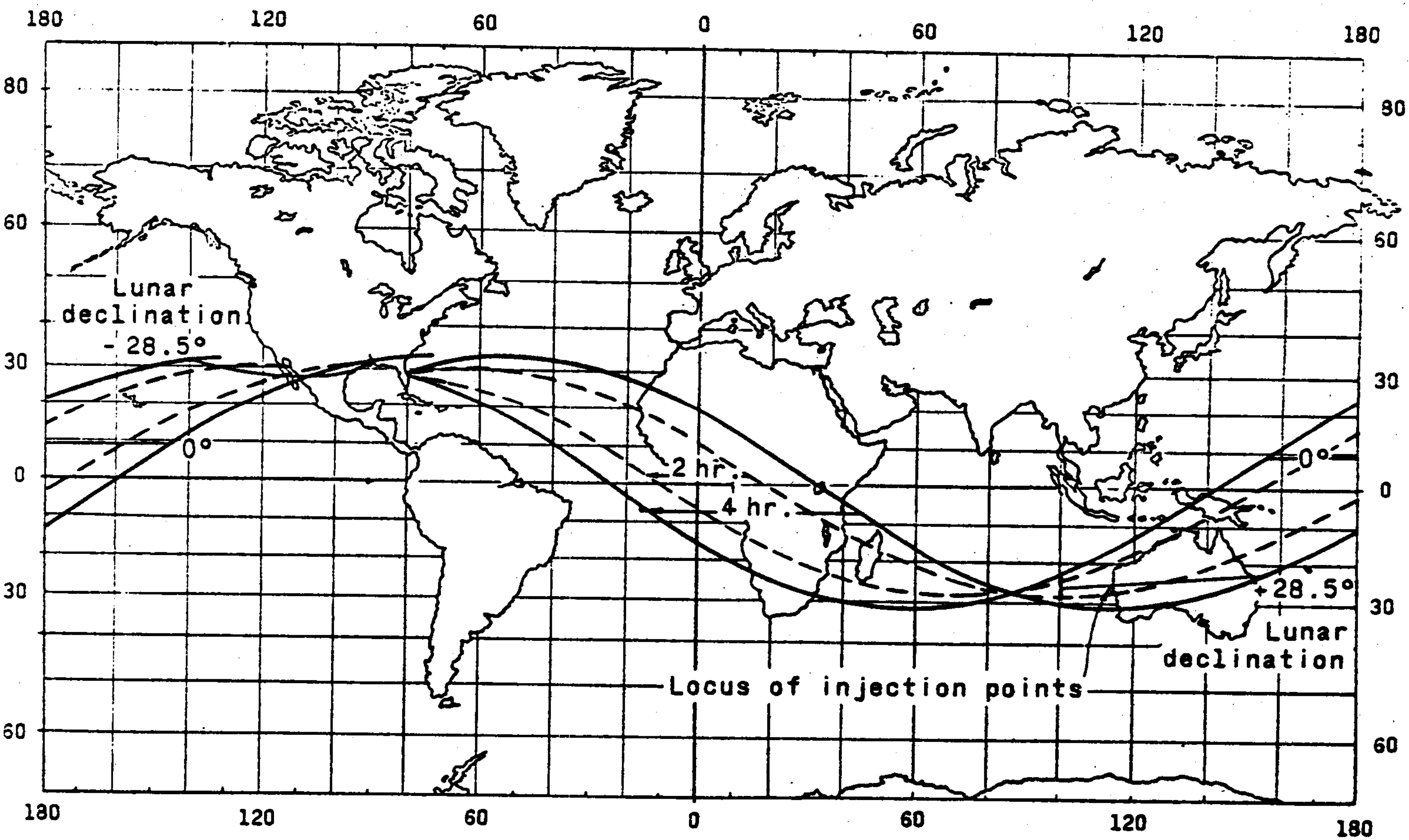
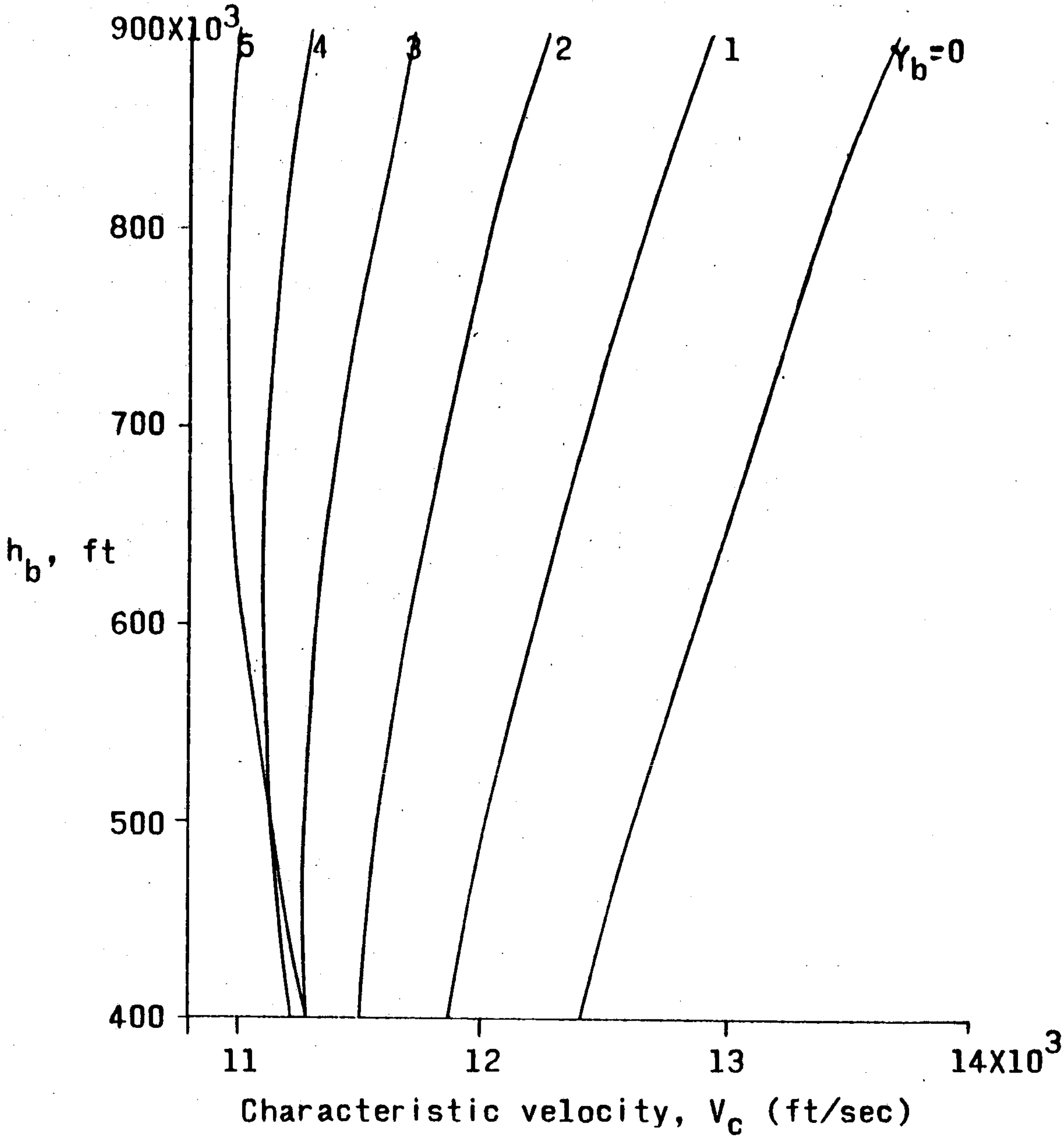


Figure 38.- Parking orbit boundaries for launch time window.

[redacted]

[redacted]

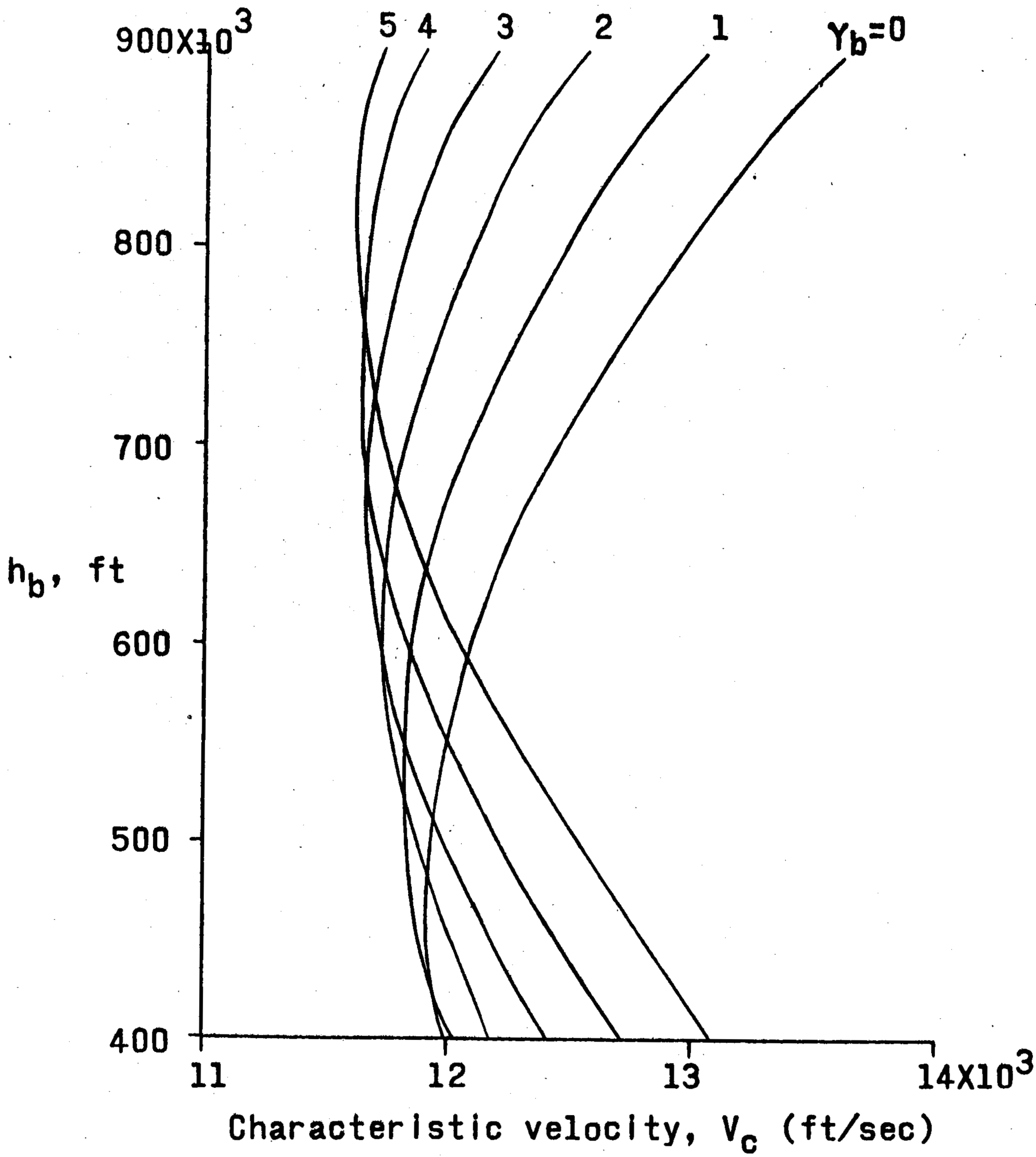


(a) $T/W = 0.5$, $I_{sp} = 420$

Figure 39.- Optimum booster performance to escape from a 600,000 ft parking orbit.

[redacted]

[redacted]

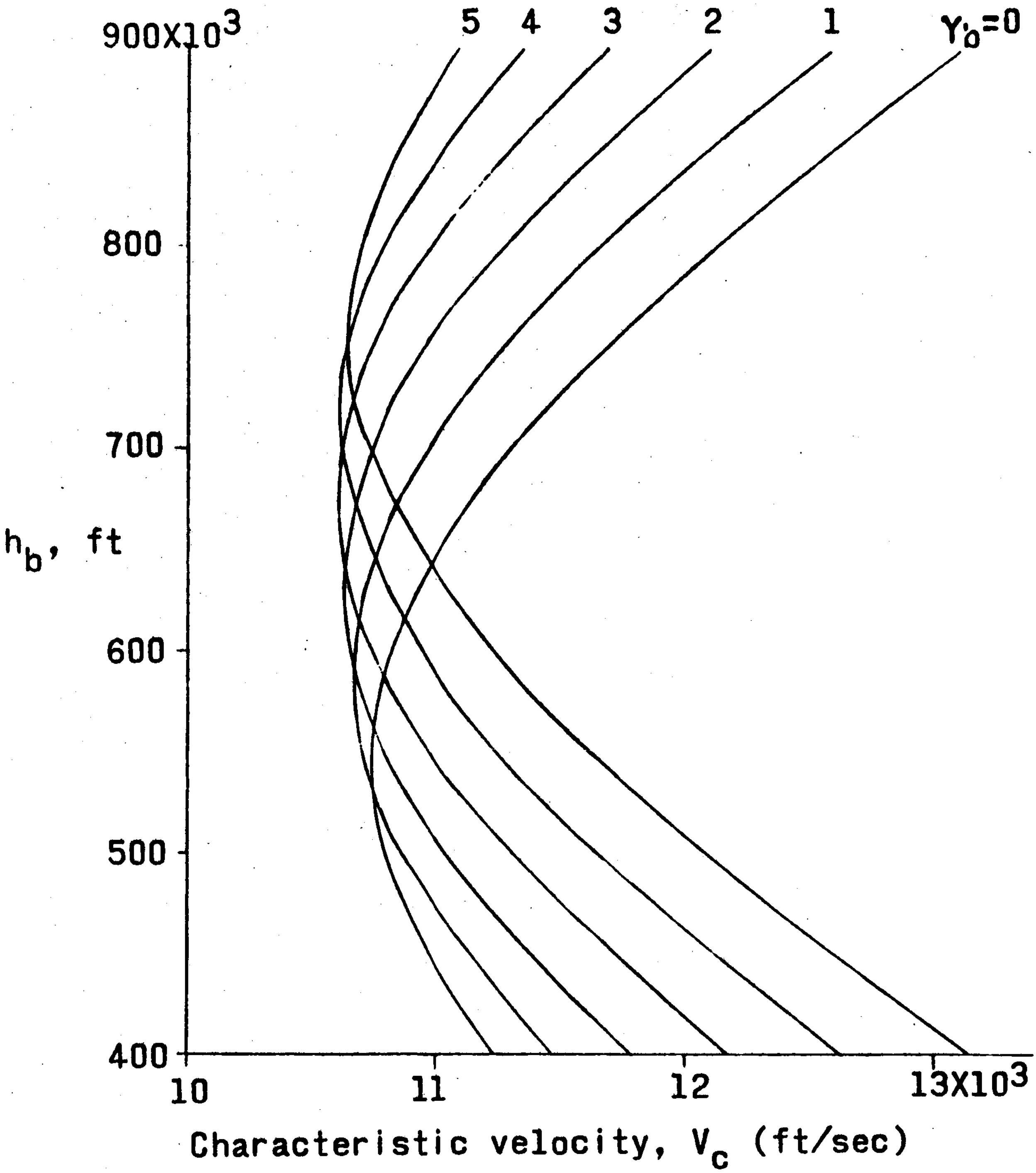


(b) T/W = 1.0, I_{sp} = 420

Figure 39.- Continued.

[redacted]

[redacted]



(c) $T/W = 1.50$, $I_{sp} = 420$

Figure 39.- Concluded.

[redacted]

[redacted]

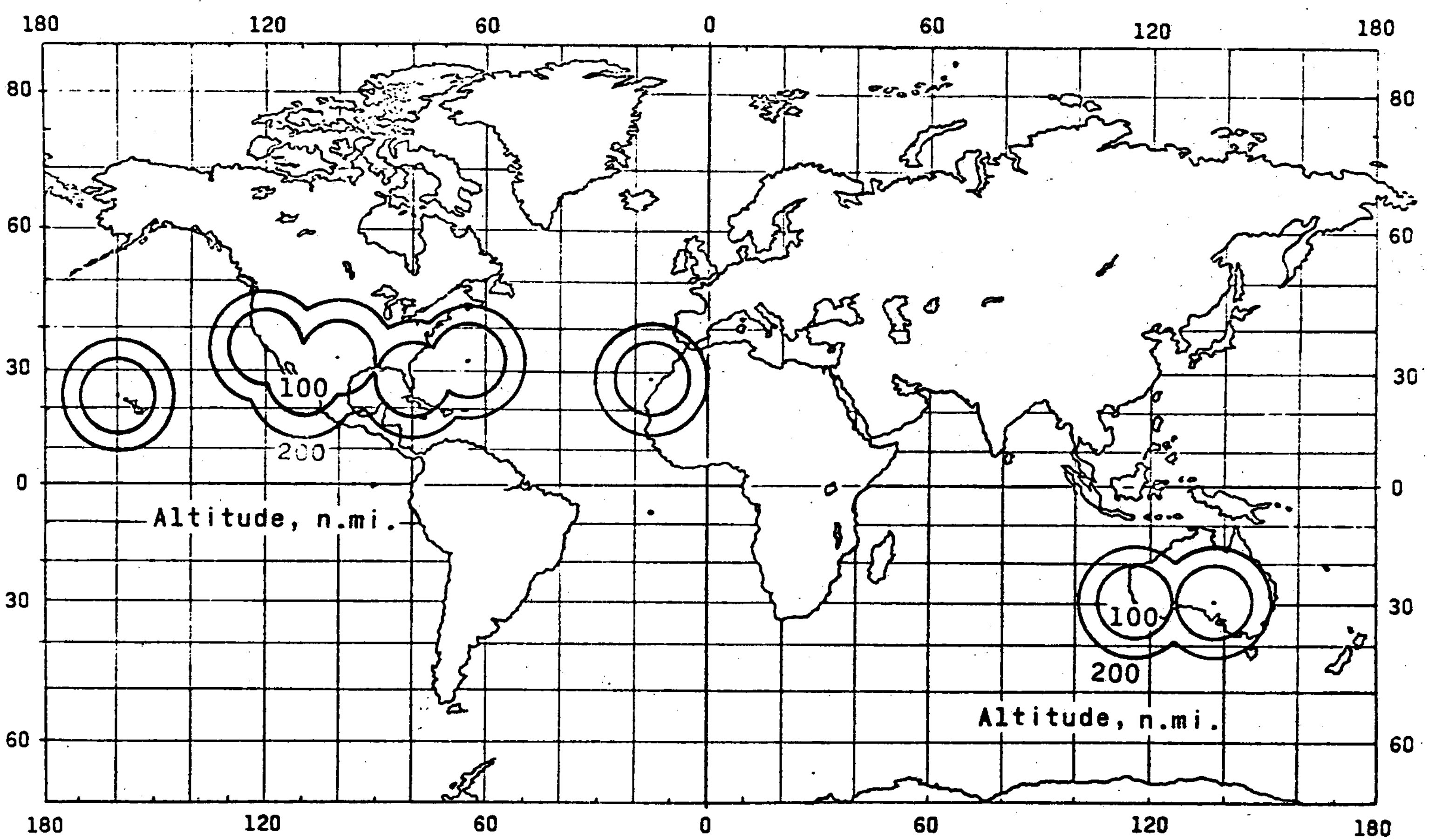


Figure 40.- Coverage of Mercury tracking network for 5° elevation angle.

[redacted]

[redacted]

Moon's orbital inclination = 28.5°

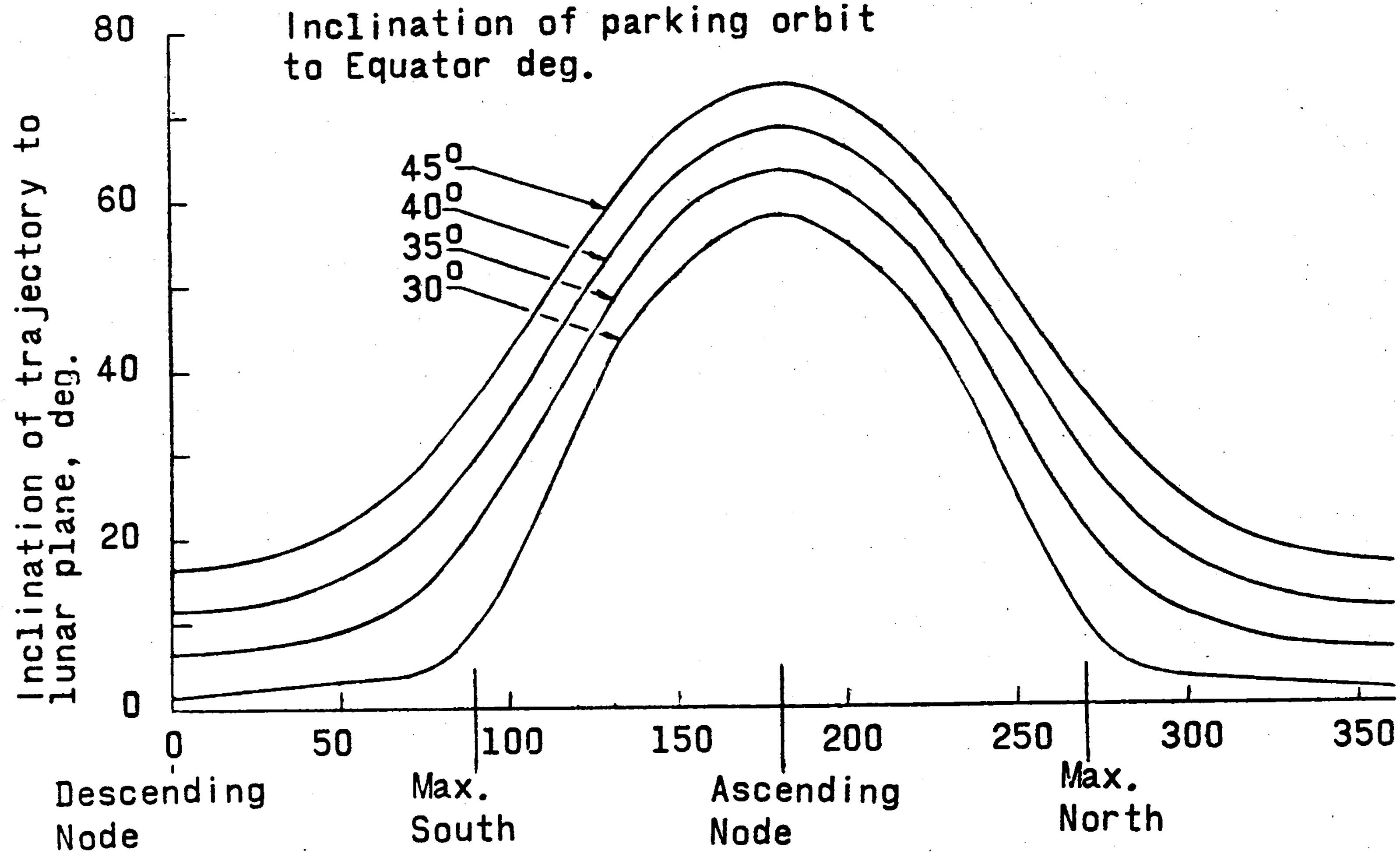


Figure 41.- Inclination of trajectory to moon's orbital plane and equatorial plane.

[redacted]

[redacted]

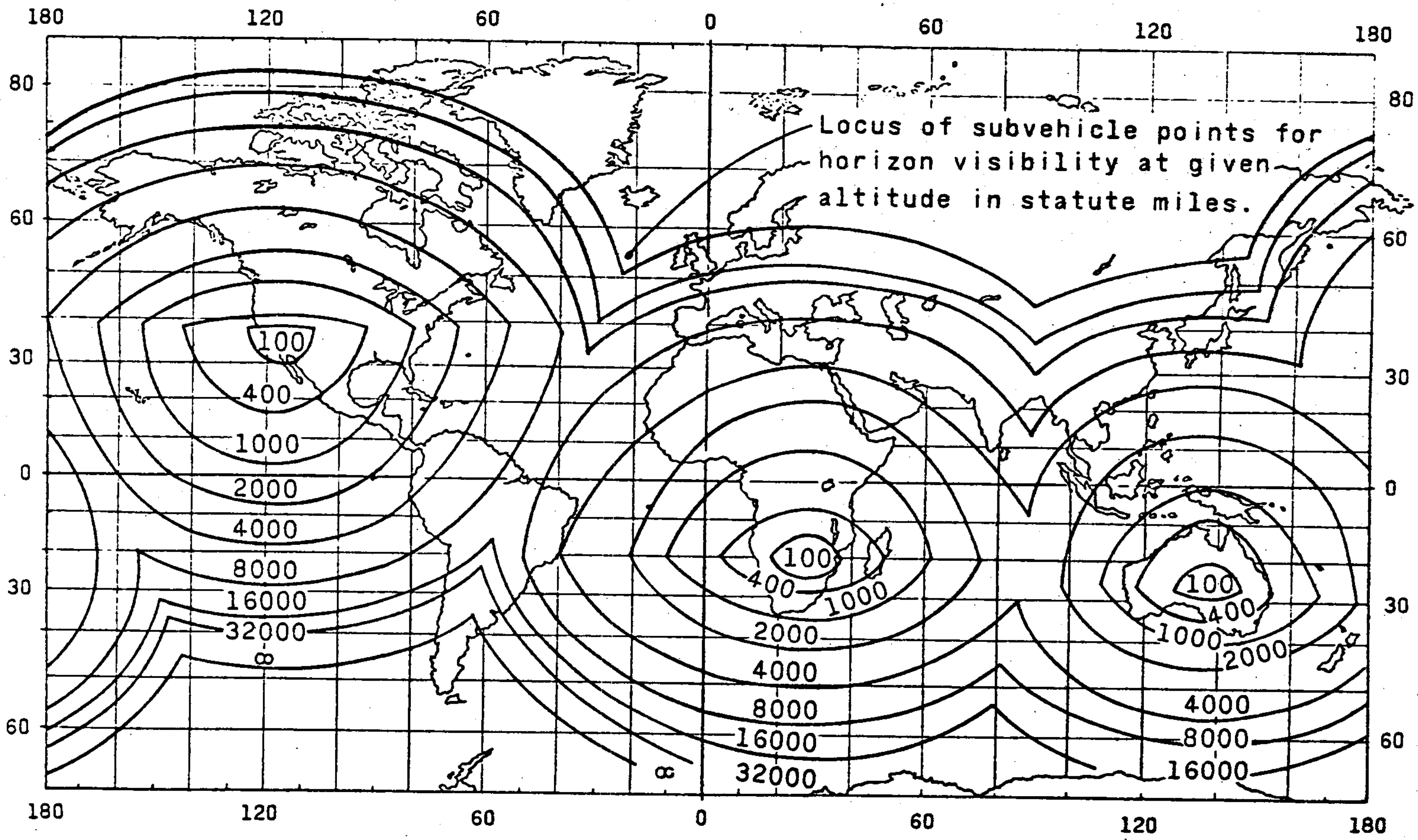


Figure 42.- Deep Space Station coverage plots for a 5° terrain horizon mask.

[redacted]

[redacted]

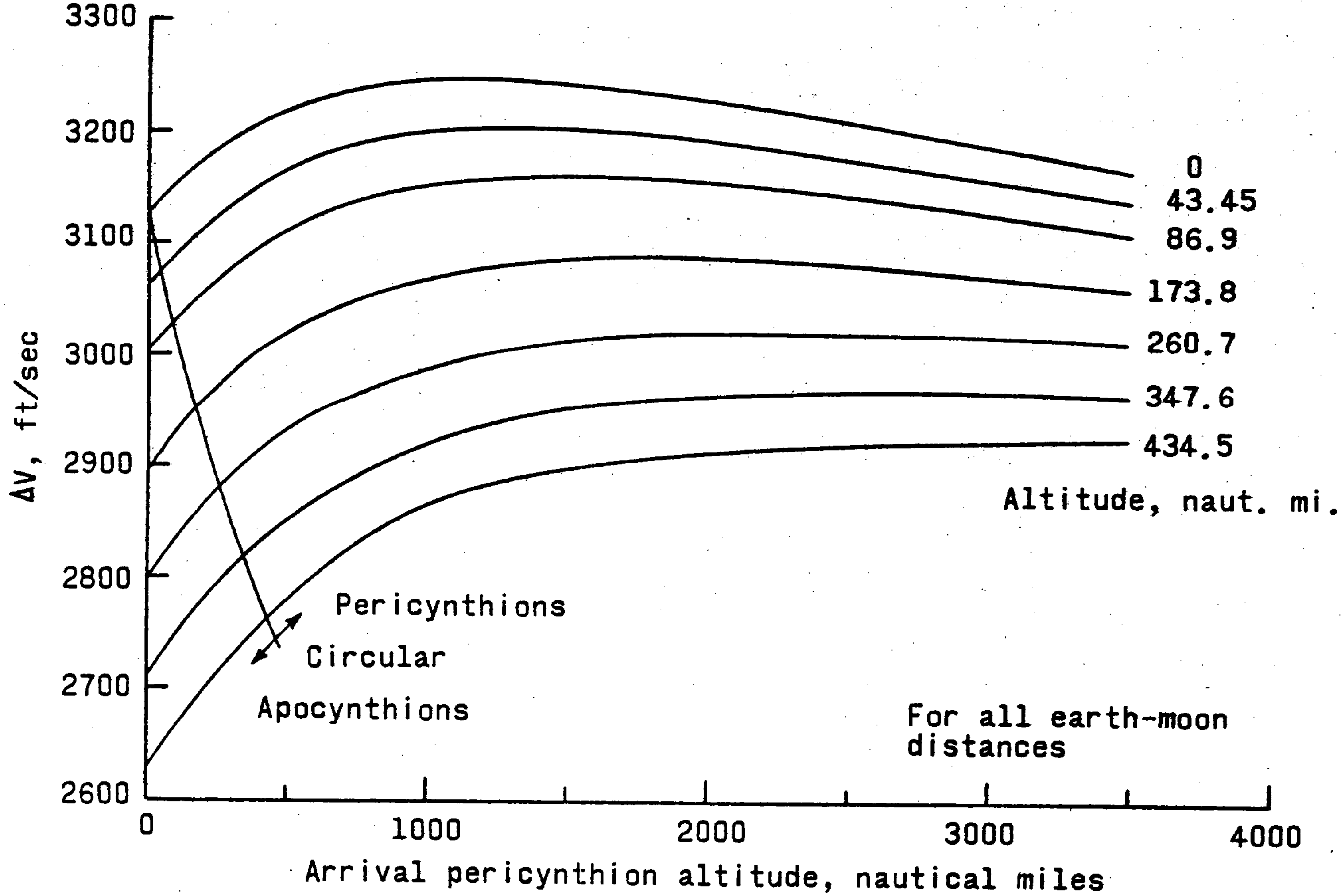
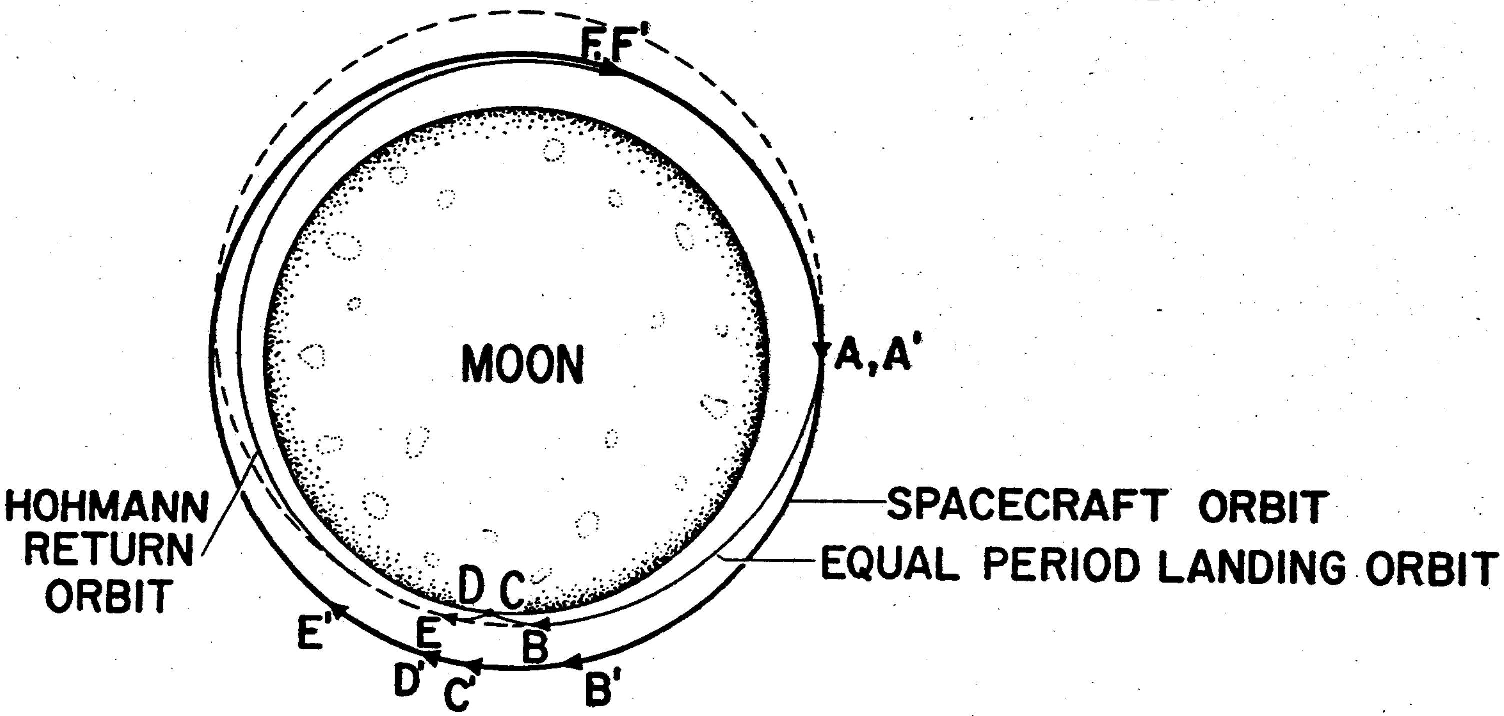


Figure 43.- Retro-velocity requirements to establish local lunar orbits from earth returning circumlunar trajectories.

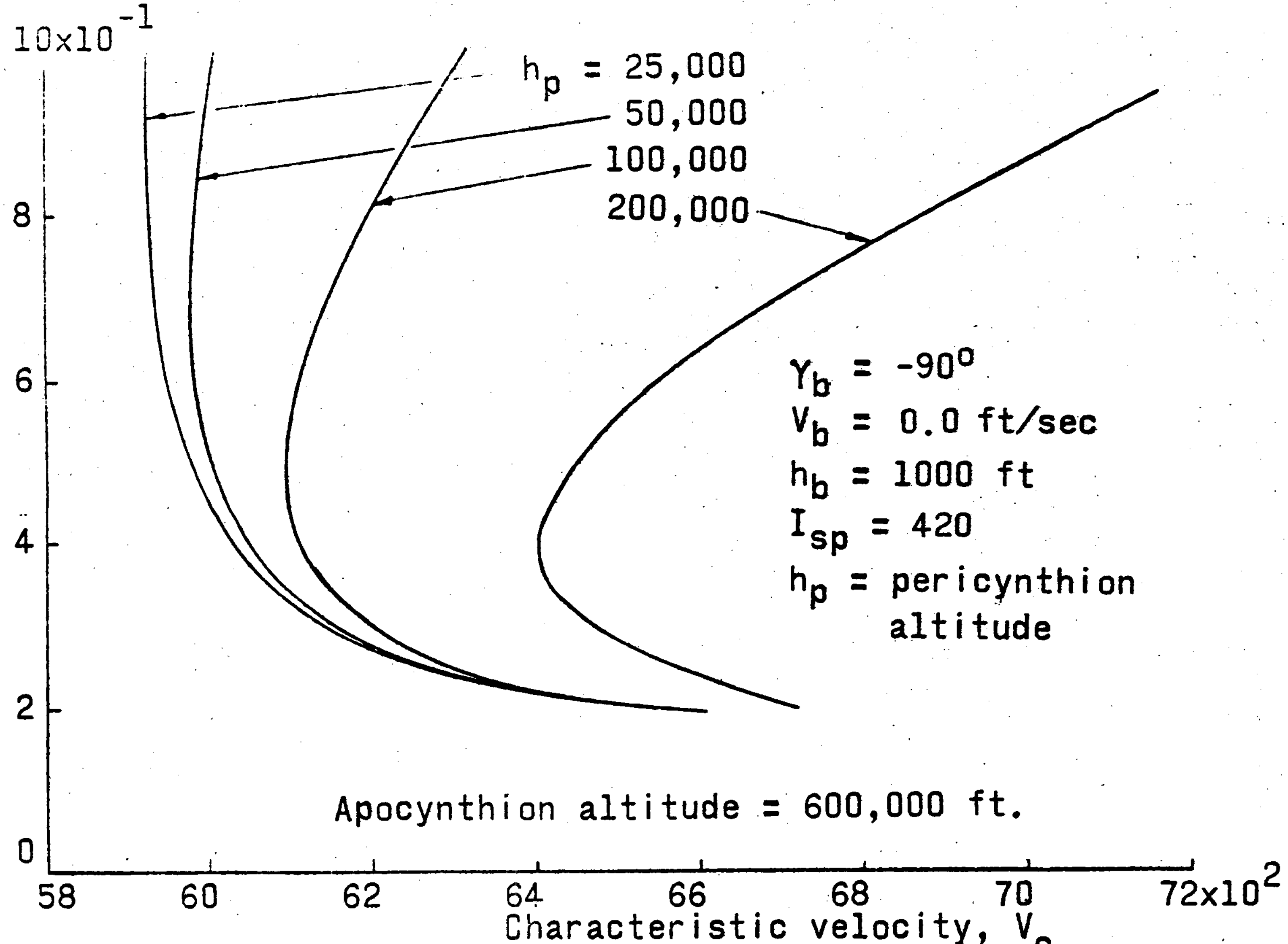
[redacted]

LUNAR LANDING TECHNIQUE VIA EQUAL PERIOD TRANSFER



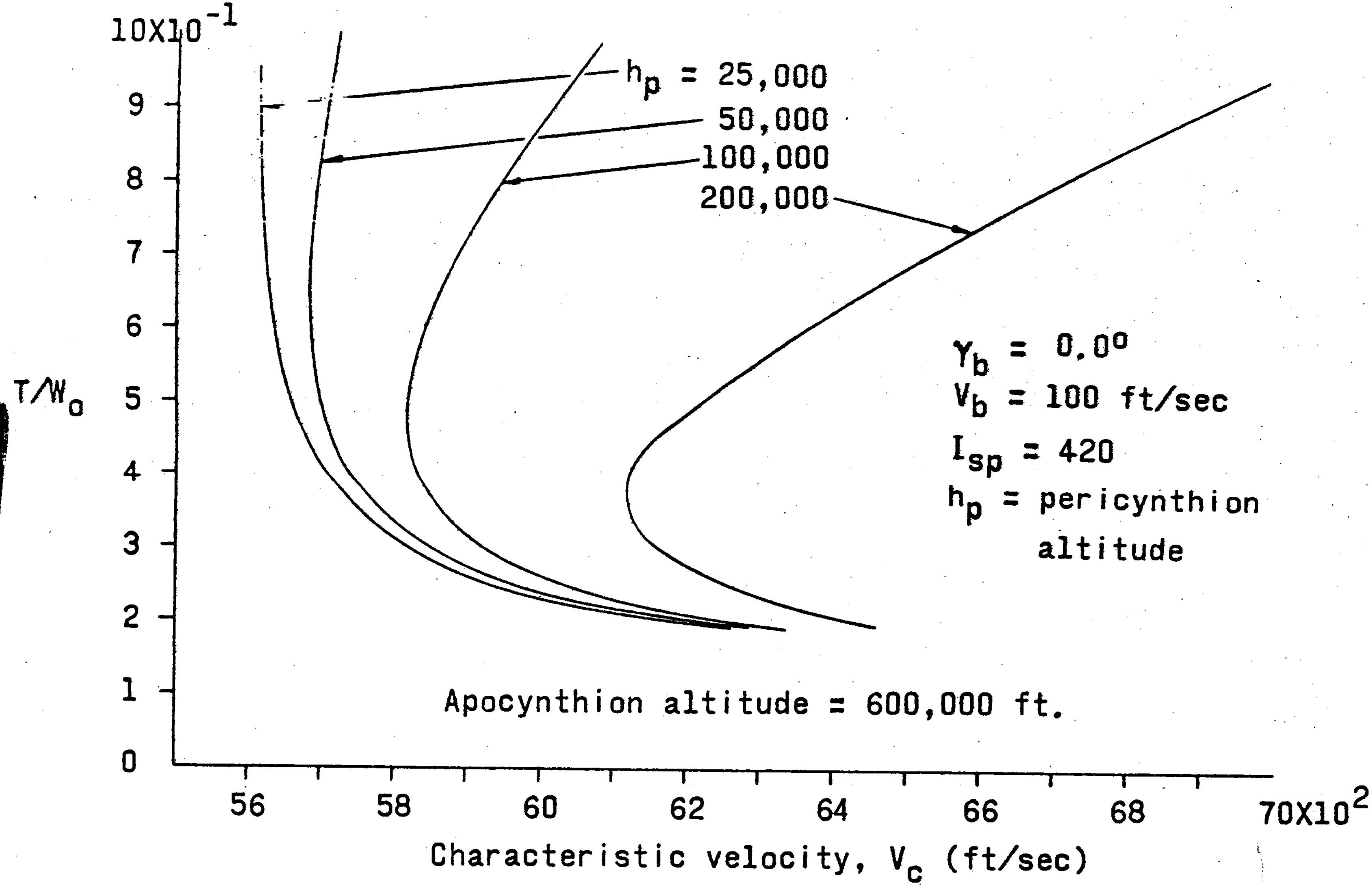
A SEPARATION OF LUNAR LANDER FROM SPACECRAFT
B INITIATION OF LANDING MANEUVER
C START OF HOVER
D ABORT FROM HOVER OR TAKEOFF FROM LUNAR SURFACE
E INSERTION INTO RETURN ORBIT
F RENDEZVOUS OF SPACECRAFT AND LUNAR LANDER

FIGURE 44. -



(a) Vertical lunar landing.

Figure 45.- Characteristic velocity for optimum lunar landings from elliptic orbits with various pericynthion altitudes.



(b) Horizontal lunar landing.

Figure 45.- Concluded.

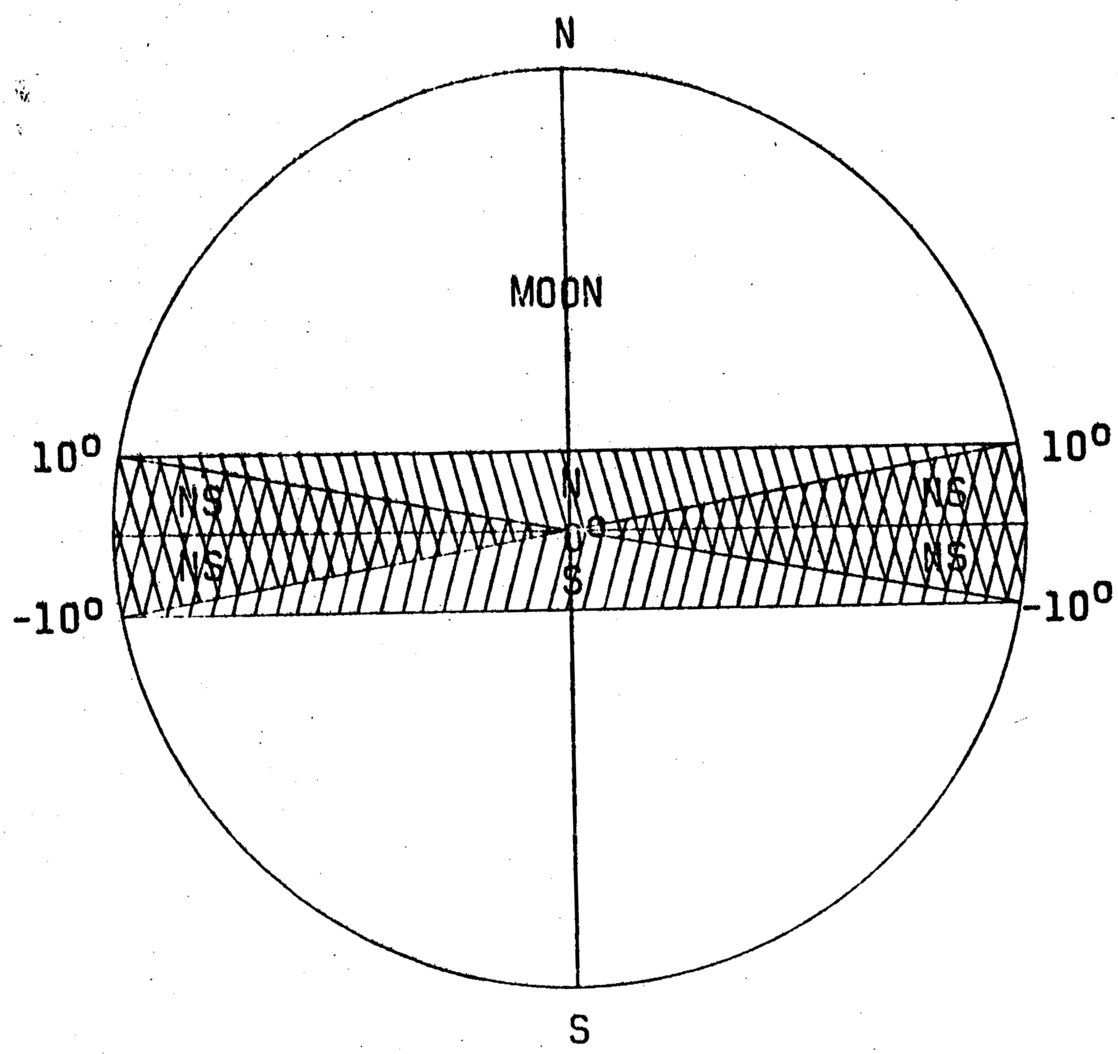


Figure 46.- Landing area for lunar mission with free return translunar trajectories - no plane changes.

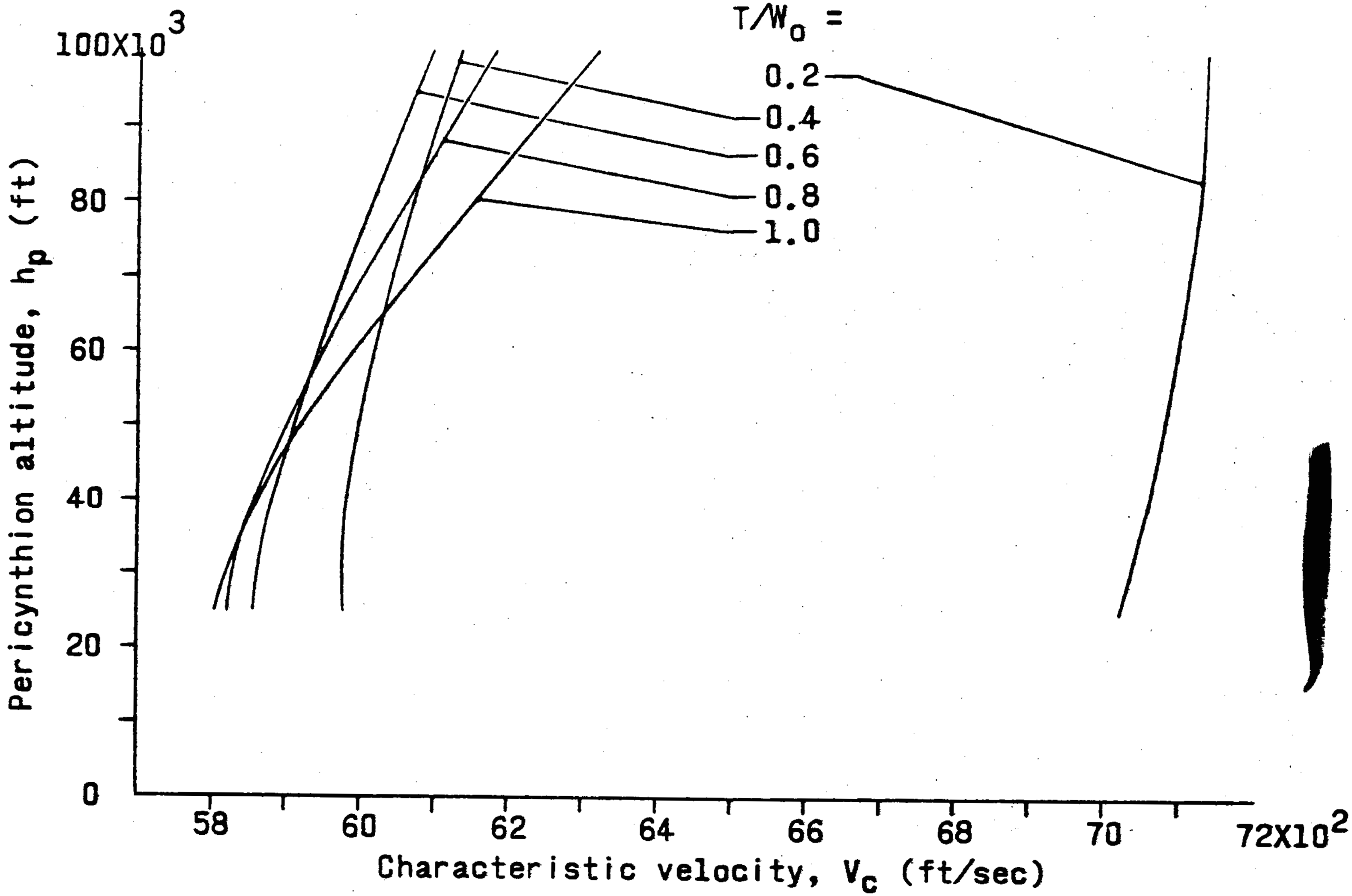


Figure 47.- Characteristic velocity for lunar launches to elliptic orbits with various T/W_o. Apocynthion altitude = 600,000 ft.

[redacted]

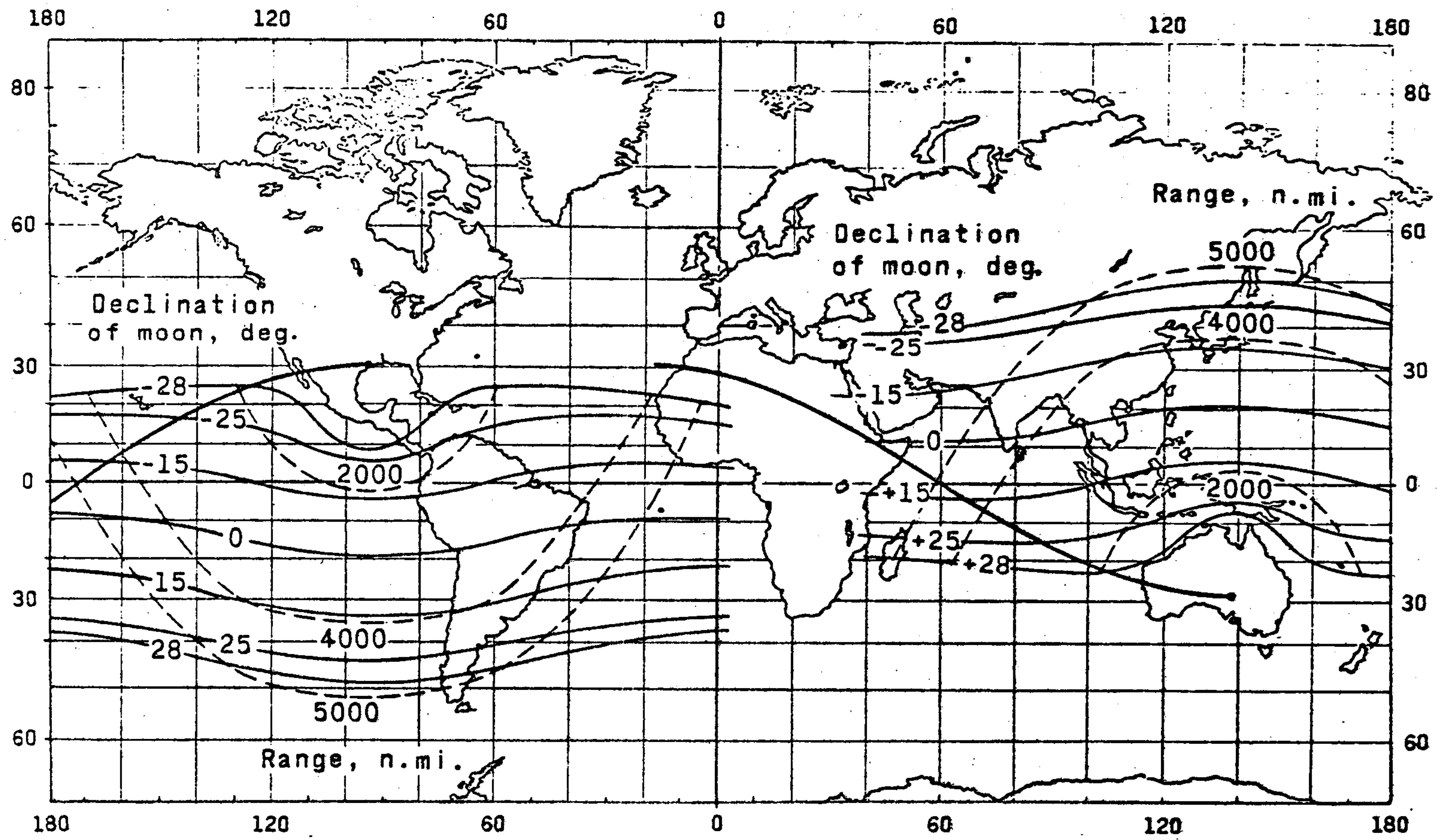
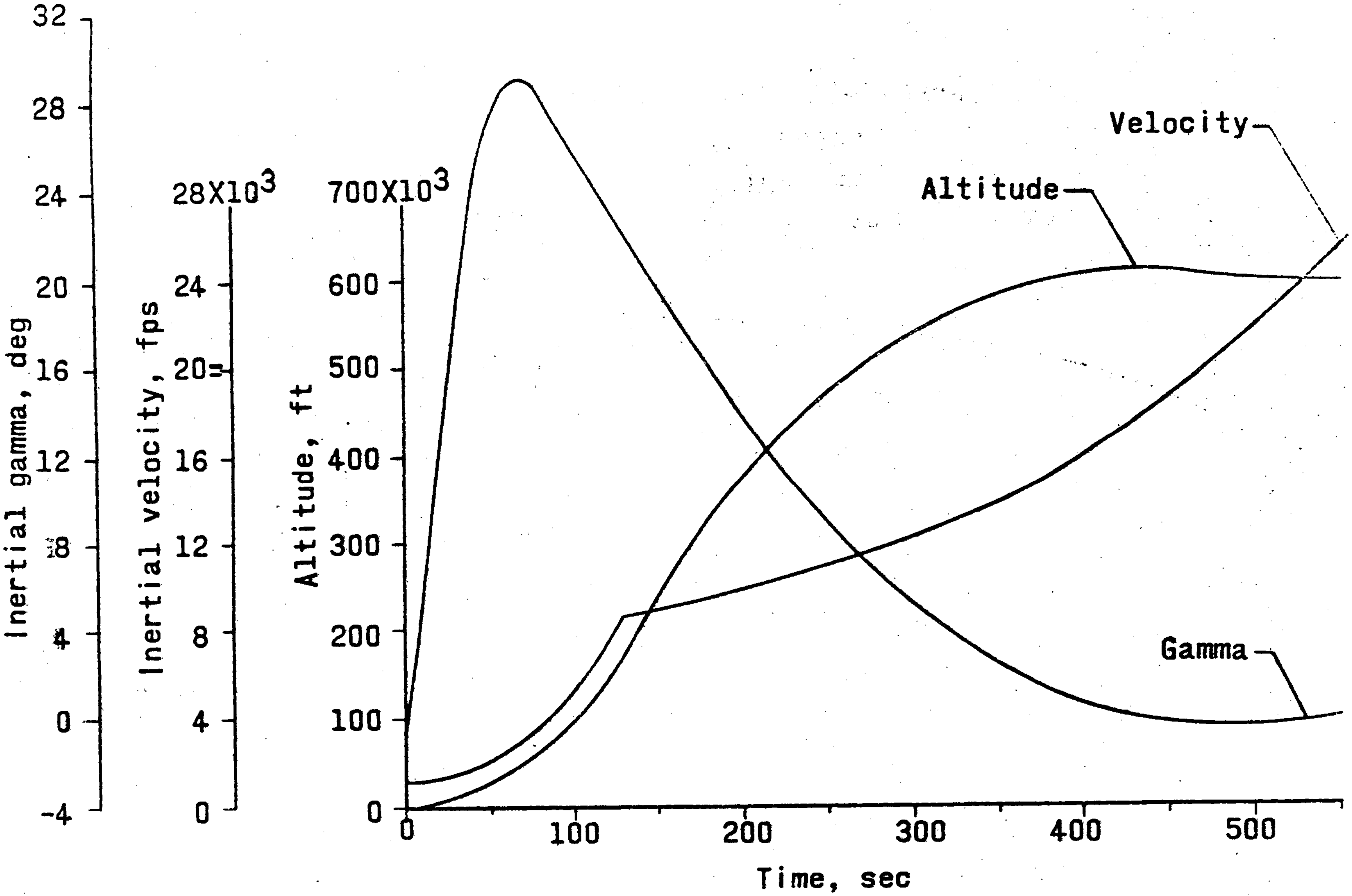


Figure 48.- Locus of reentry points for landing sites in U.S.A. and Australia.

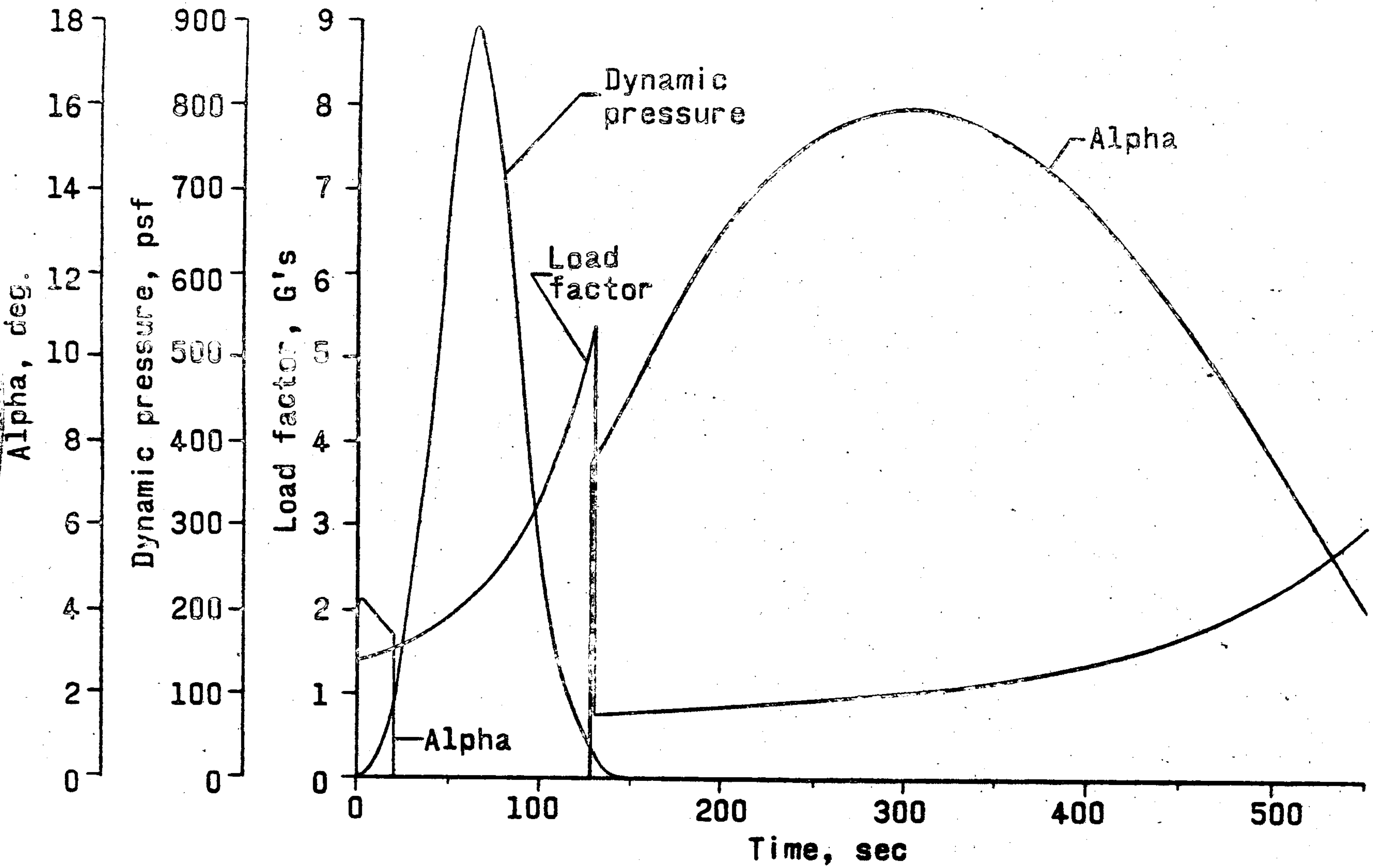
[redacted]TIAL



(a) Flight path.

Figure 49.- Time history from lift-off to parking orbit.

[redacted]



(b) Loads.

Figure 49. - Concluded.

[redacted]

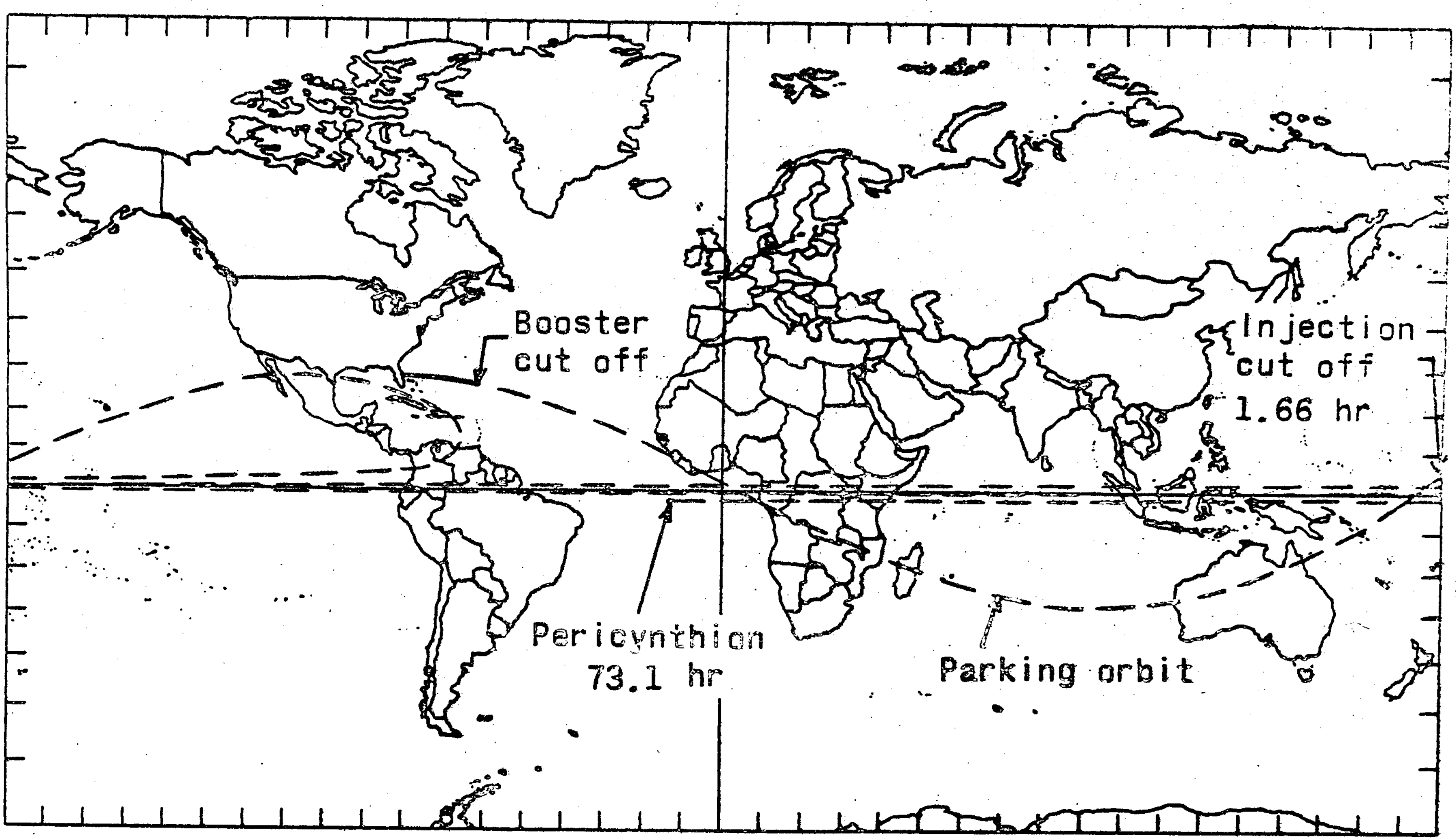


Figure 50.- Earth track for lunar flight plan.

[redacted]

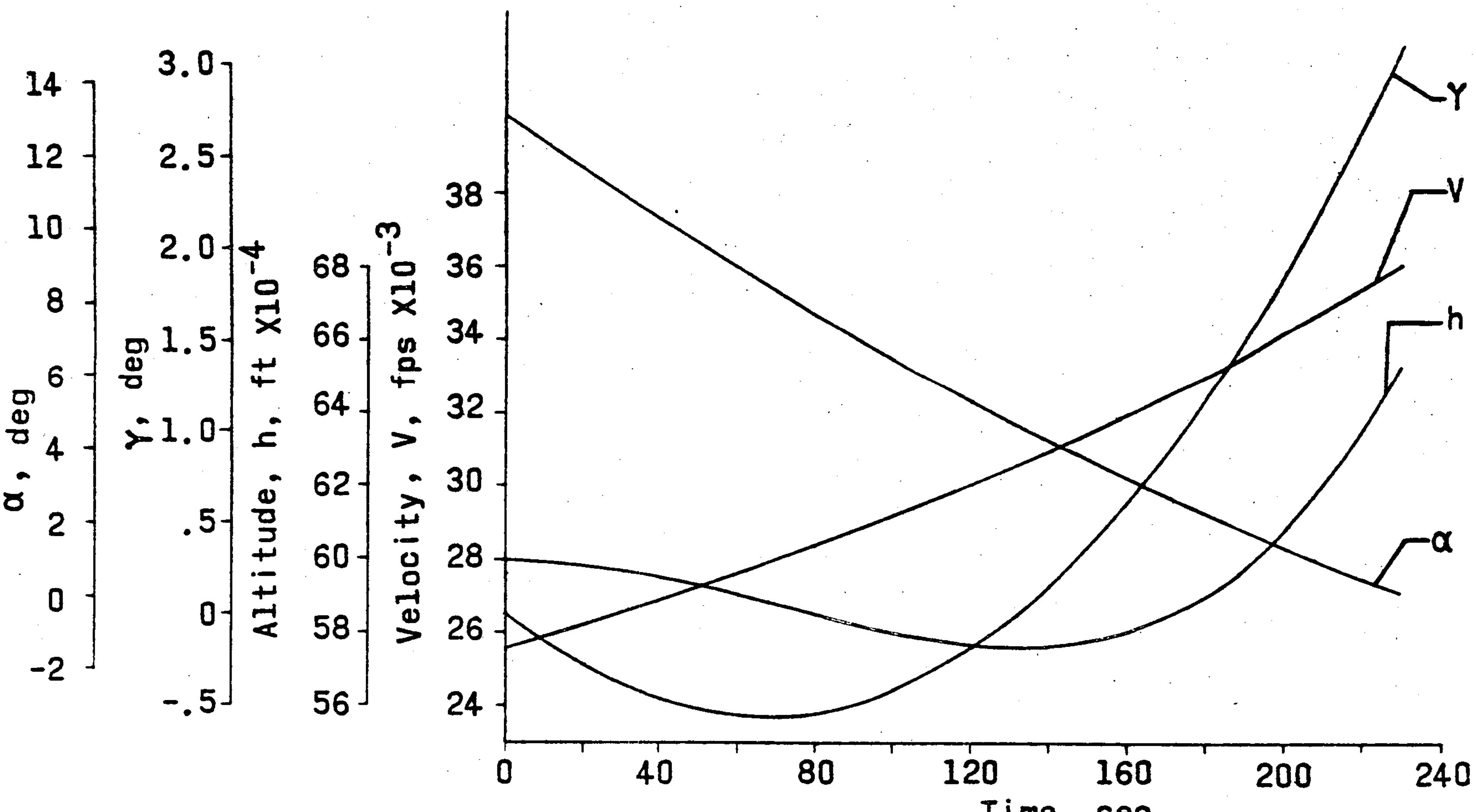


Figure 51.- Time history of transfer from parking orbit to translunar trajectory.

[redacted]

[redacted]

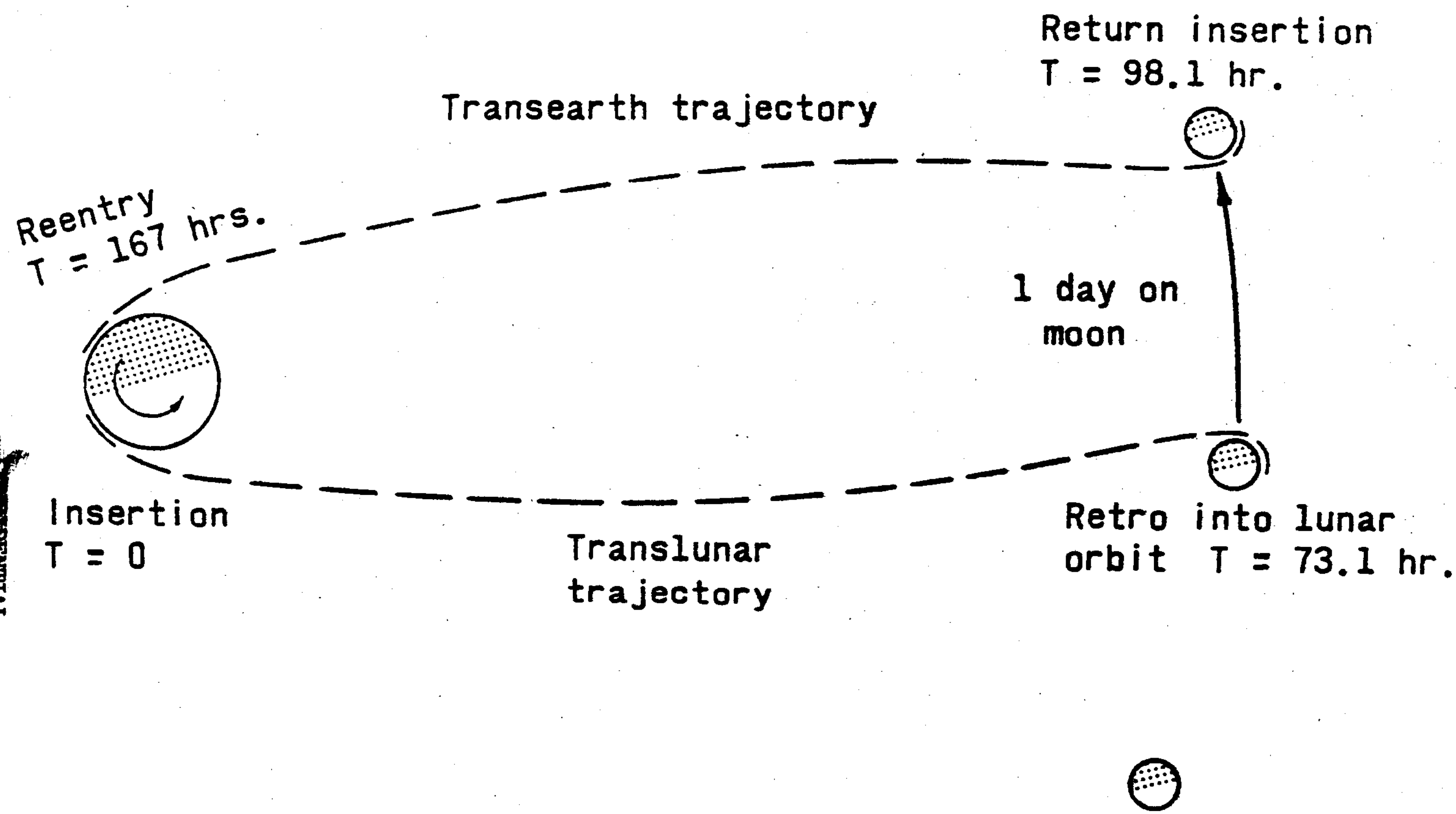


Figure 52.- Translunar and transearth trajectories shown in the inertial Earth-Moon system.

[redacted]

[redacted]

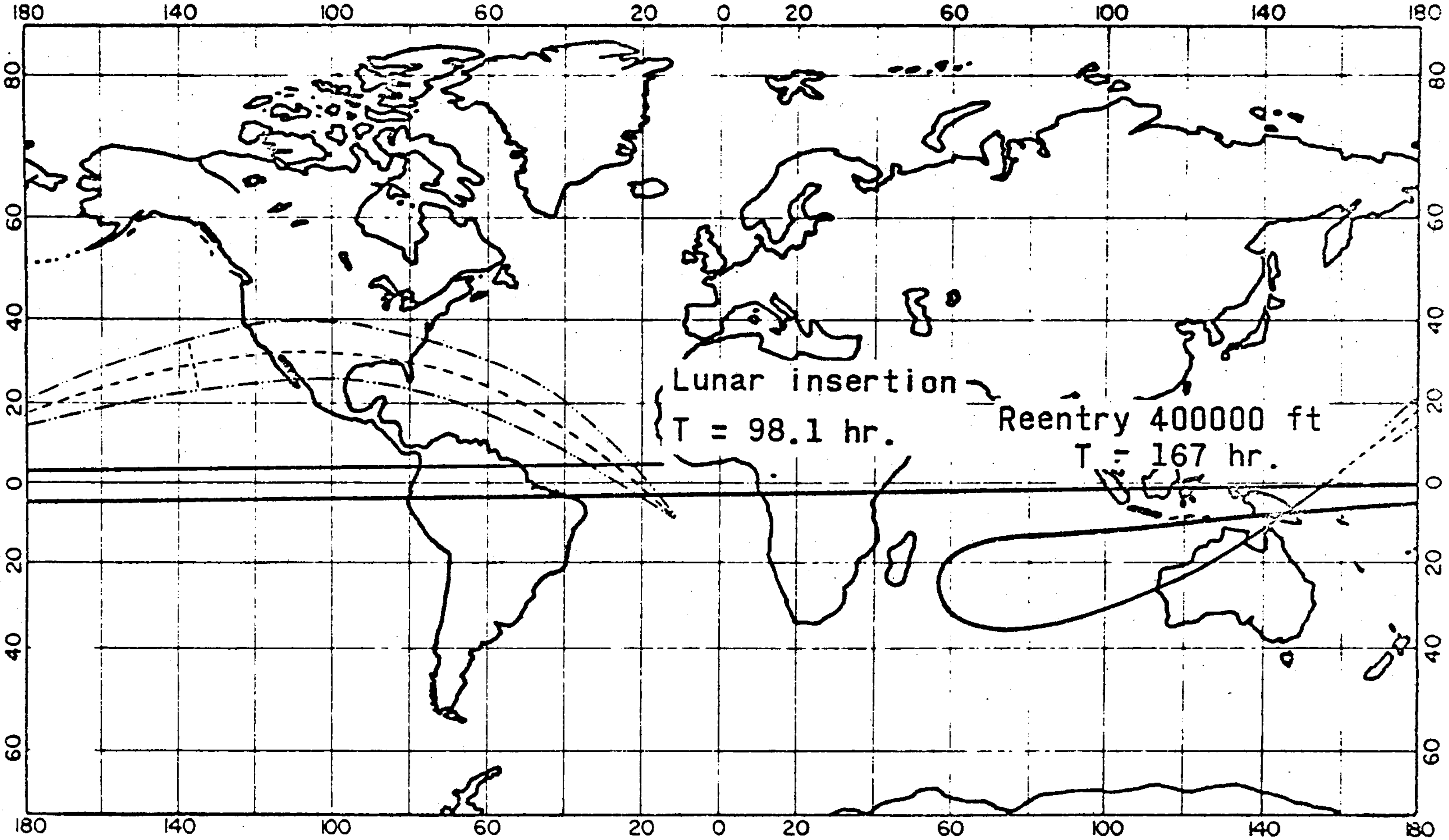


Figure 53.- Earth track of transearth and reentry phases.

[redacted]

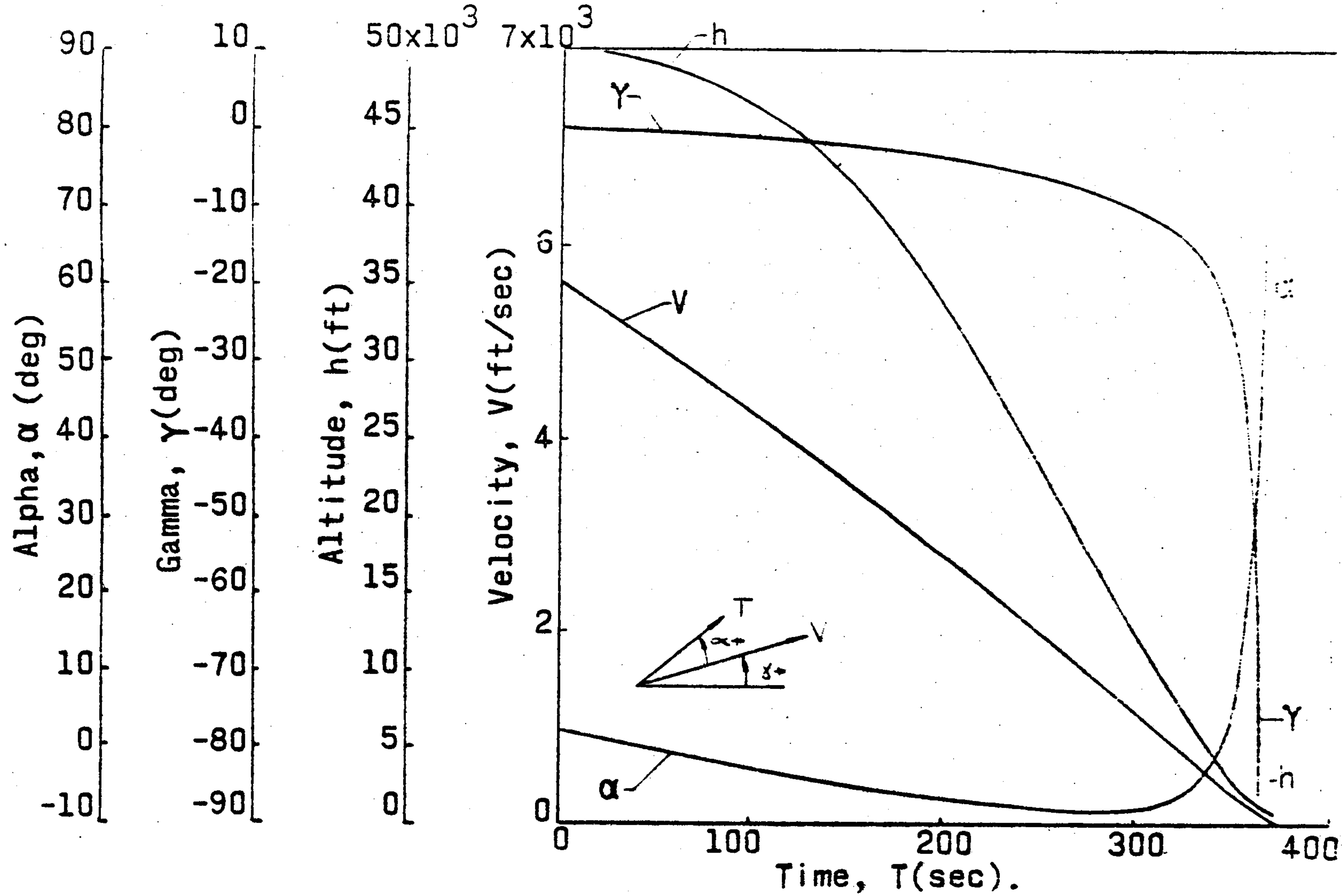


Figure 54.- Time history for optimum vertical lunar landing from 50,000 ft pericynthion. $\gamma_b = -90^o$, $V_b = 0.0$ fps, $h_b = 650$ ft, $T/W_o = 0.4$, Isp = 420. Apocynthion altitude = 600,000 ft.

[redacted]

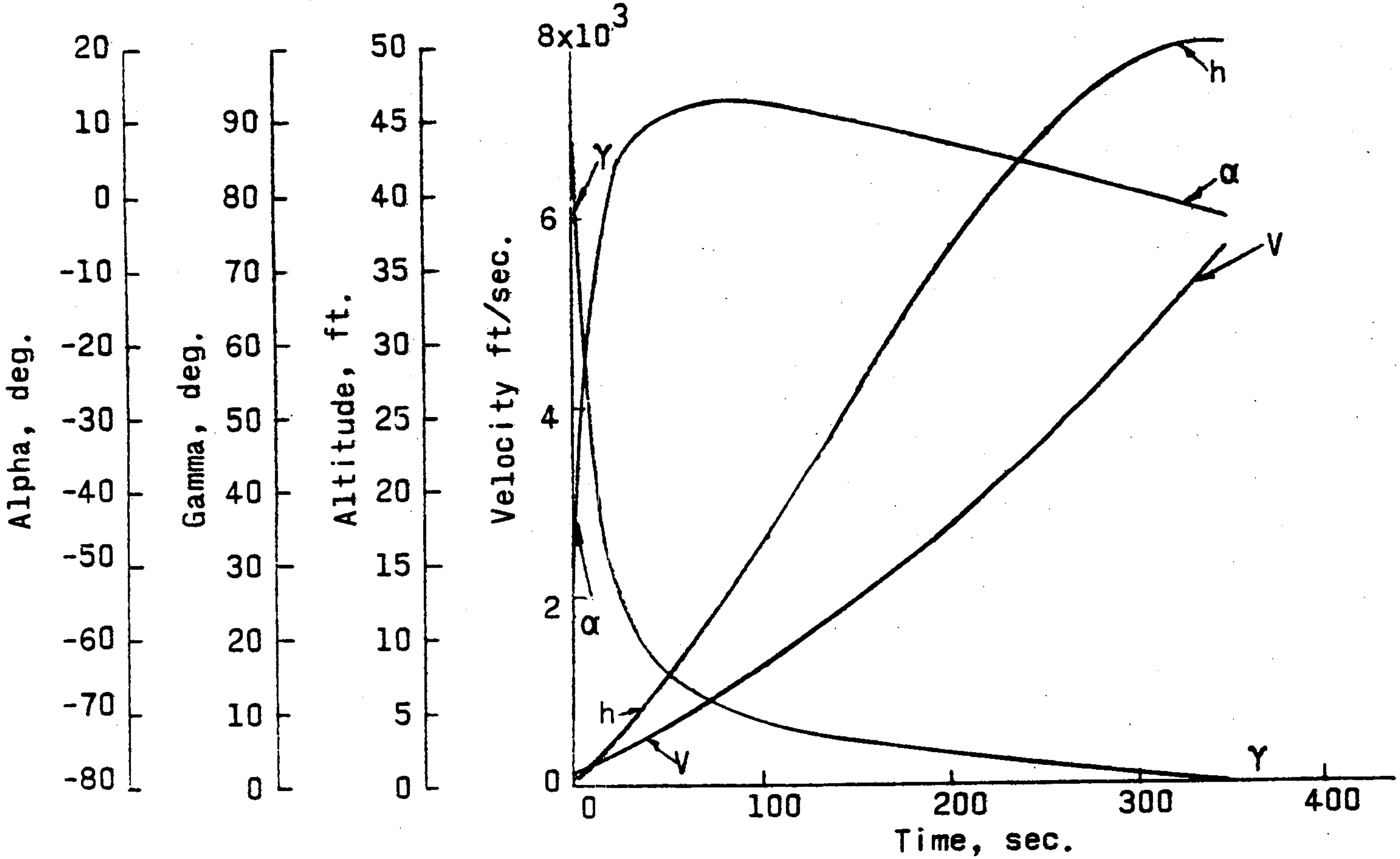


Figure 55.- Time history for optimum lunar launch to 50,000 ft. pericynthion. $\gamma_b = 0.0^o$, $V_b = V_p$, $T/W_o = 0.4$, $I_{sp} = 305$, apocynthion altitude = 600,000 ft

[redacted]

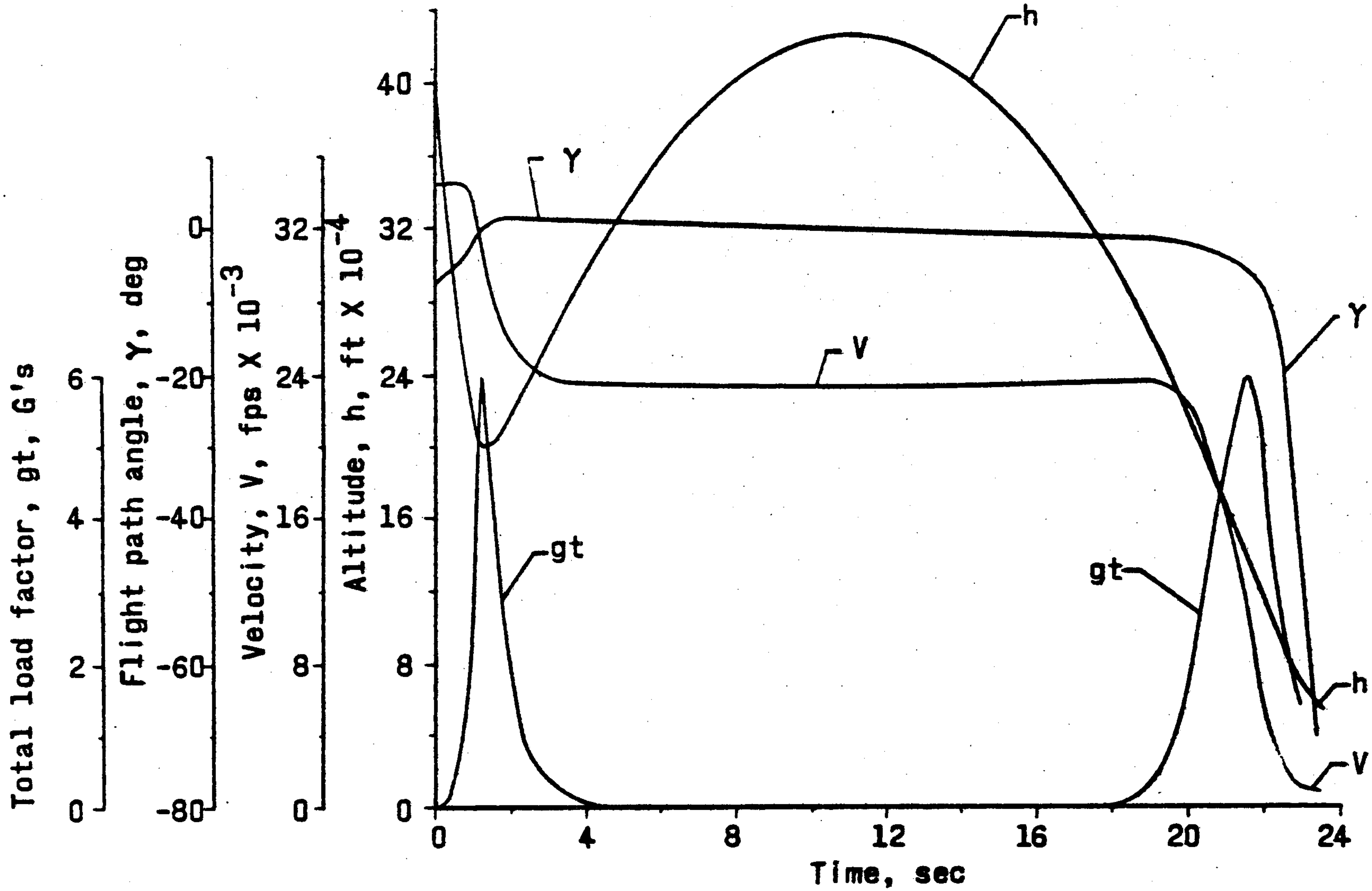


Figure 56.- Time history from reentry to near-landing.

[redacted]

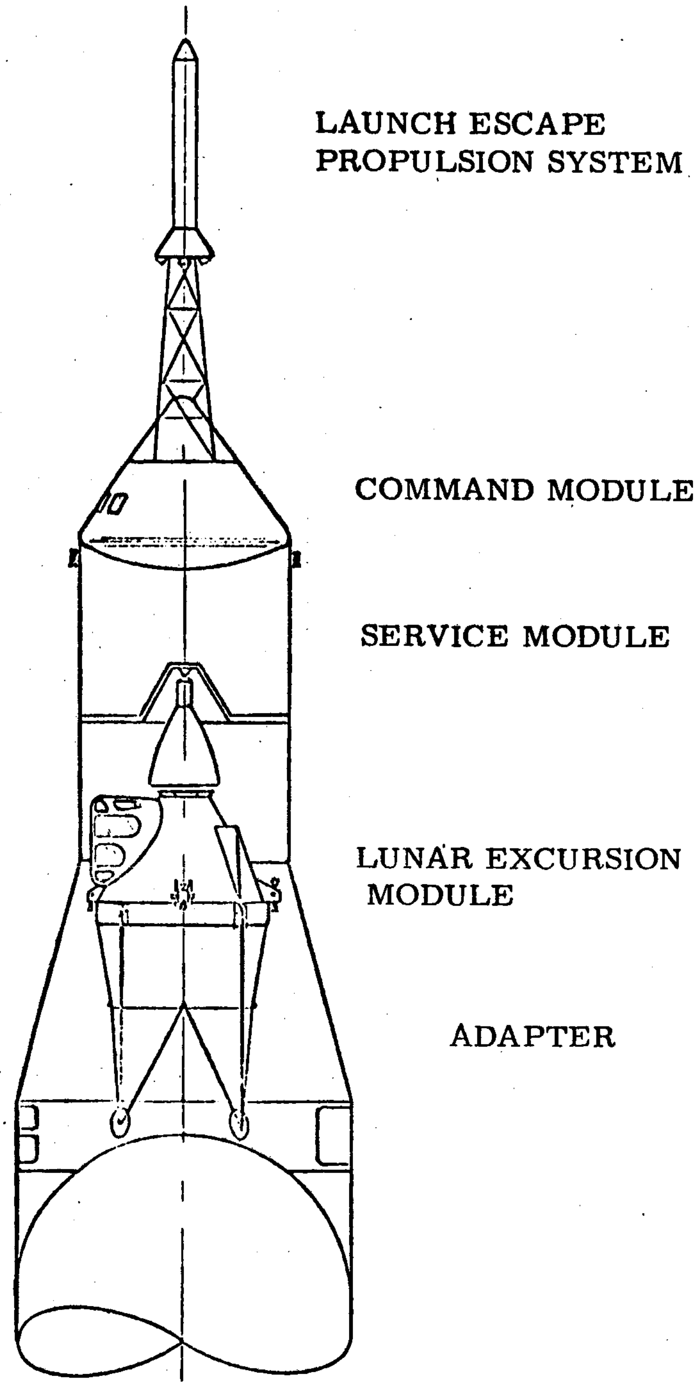


FIGURE 57. - GENERAL ARRANGEMENT LUNAR LANDING CONFIGURATION

[redacted]

[redacted]

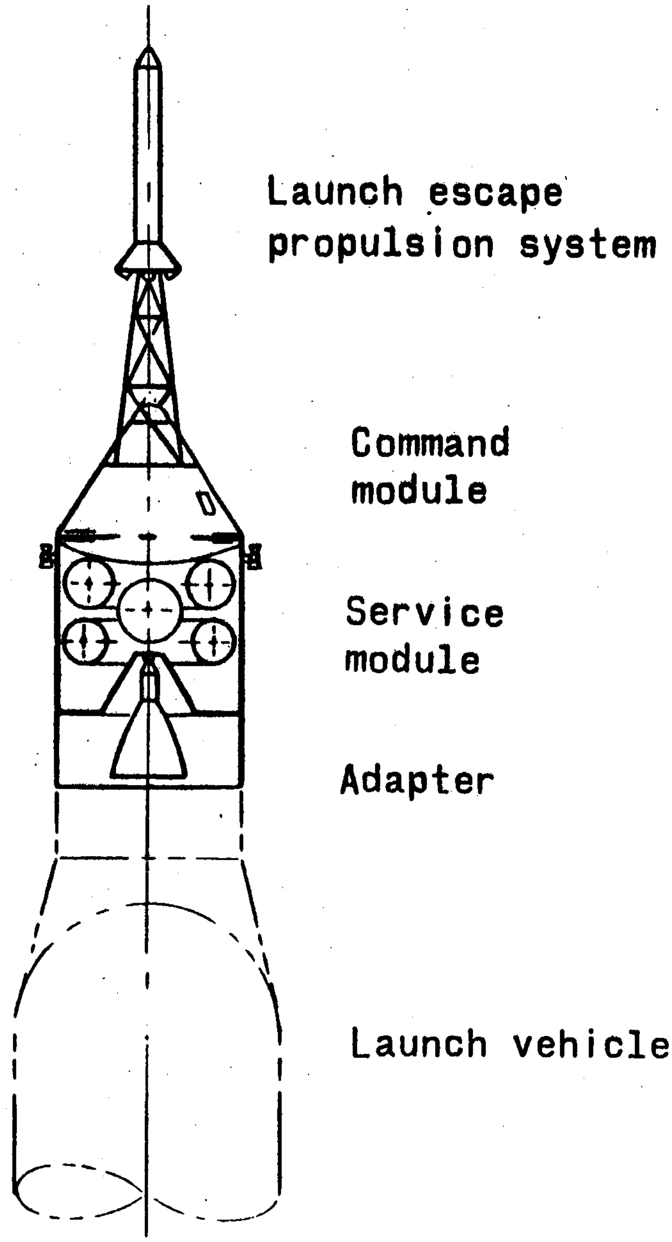


Figure 58.- General arrangement -
earth orbital configuration.

[redacted]

[redacted]

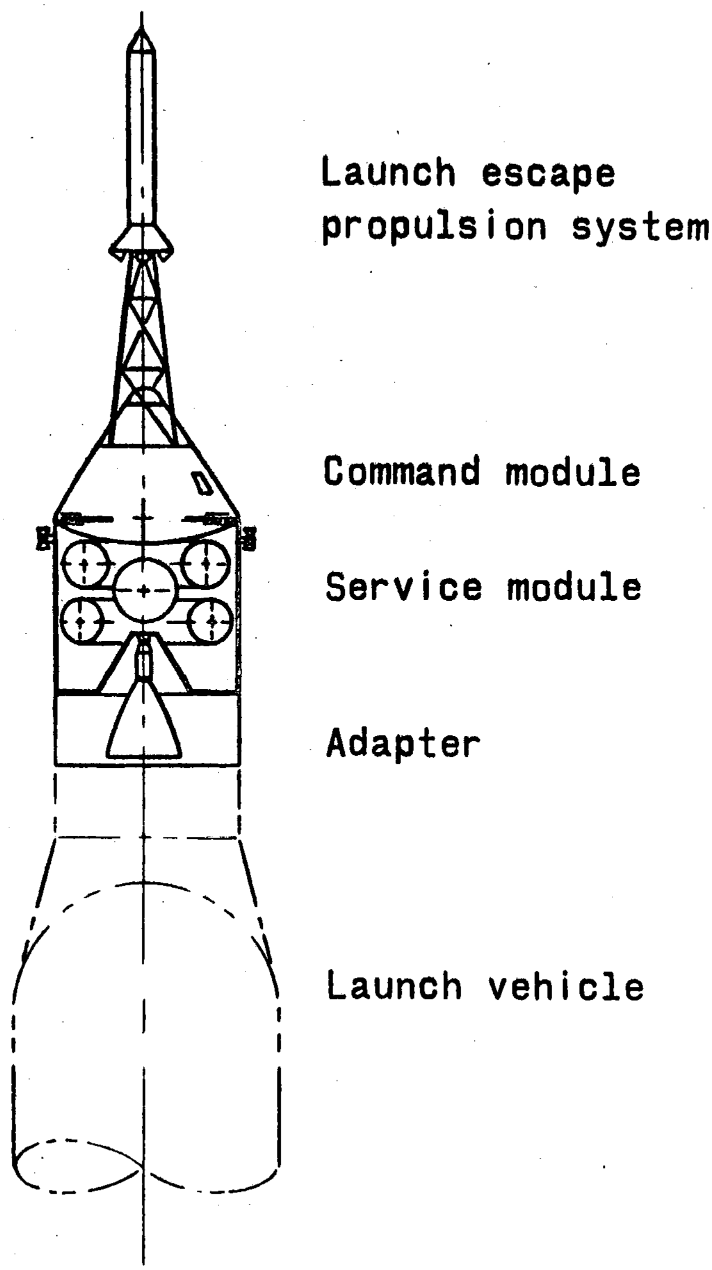


Figure 60.- General arrangement - circumlunar configuration.

[redacted]

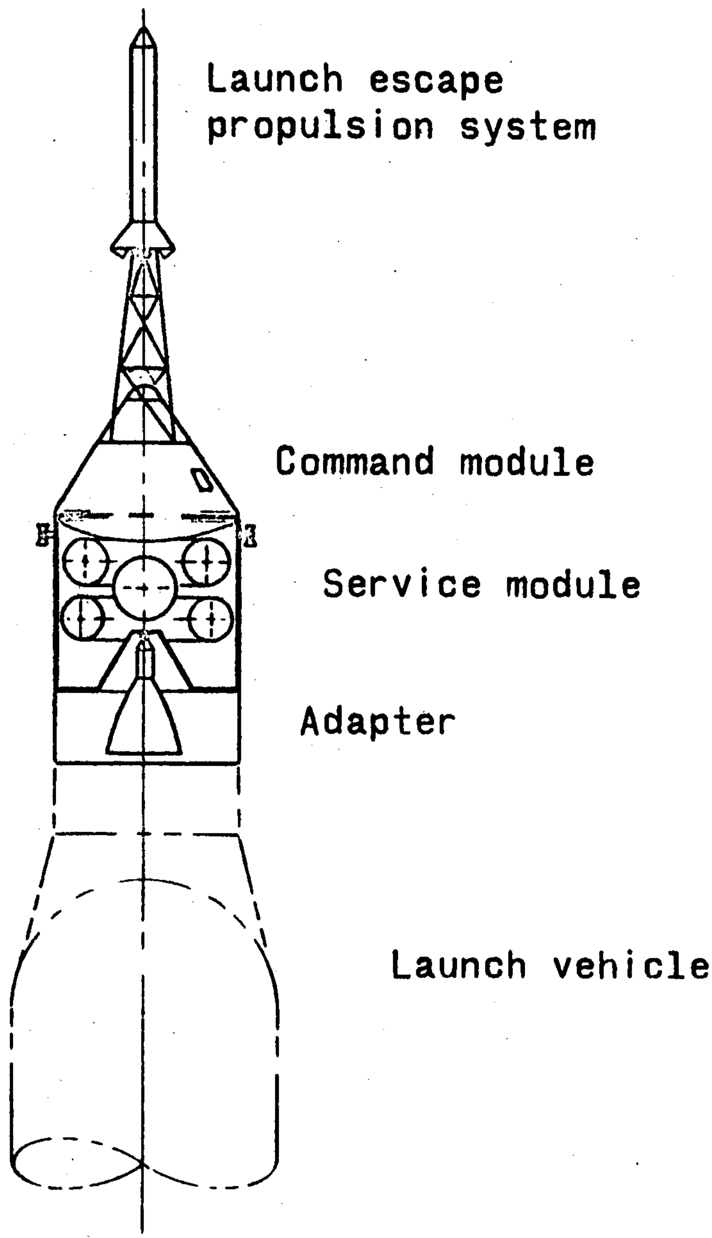


Figure 61.- General arrangement -
lunar orbital configuration.

[redacted]

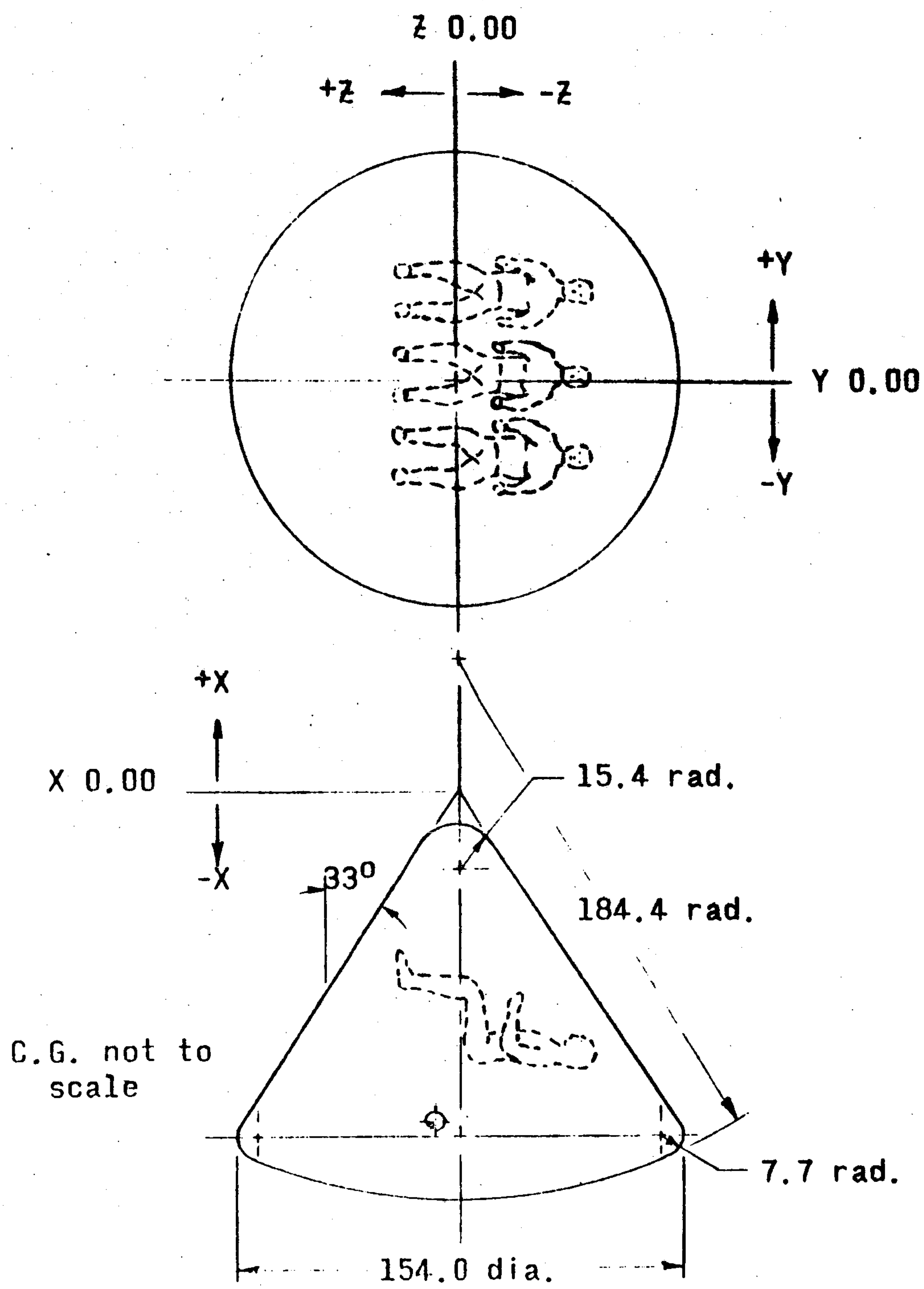


Figure 62.- Command module nominal geometry.

[redacted]

[redacted]

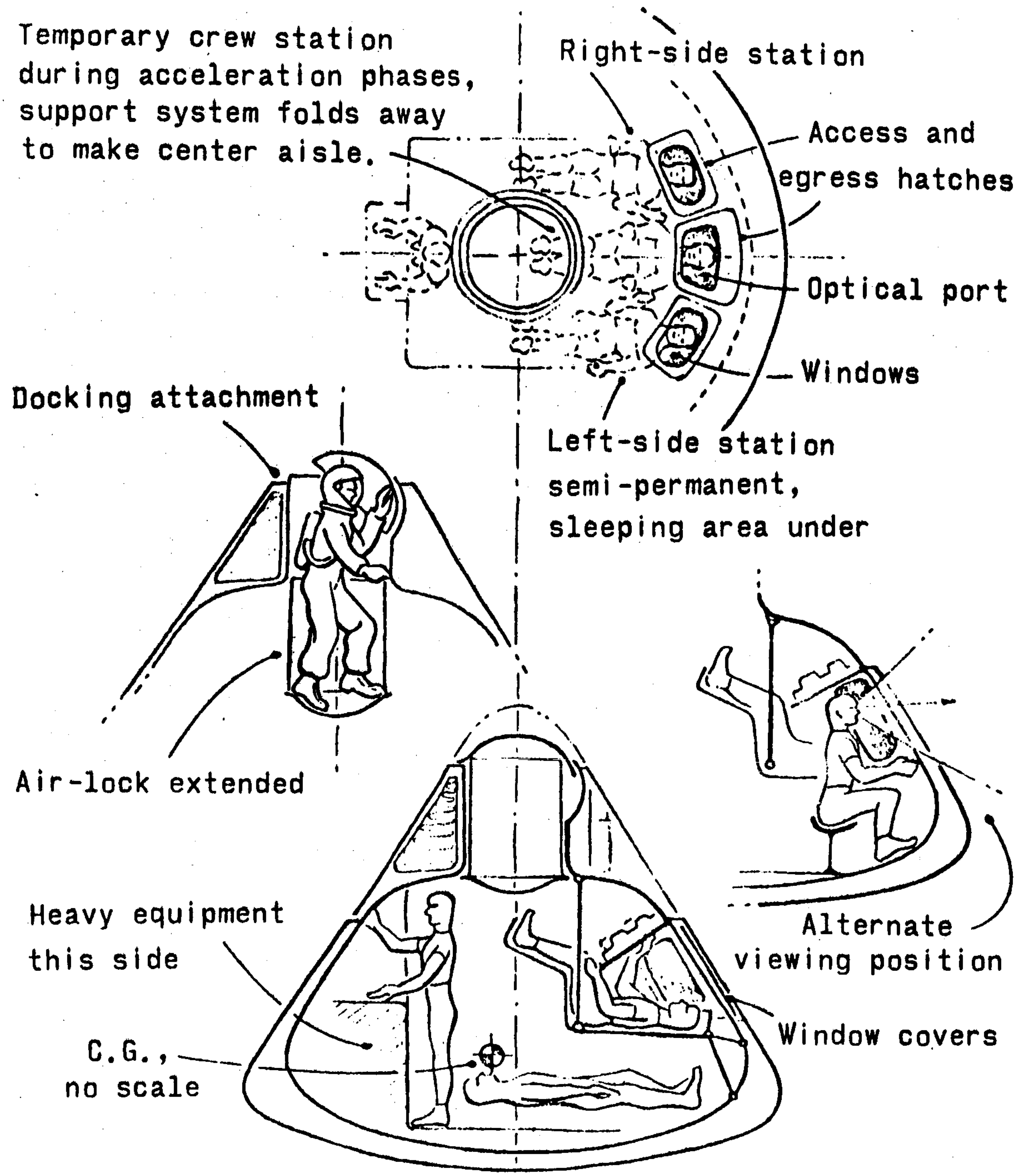


Figure 63.- Command module - Inboard profile, activity areas.

[redacted]

[redacted]

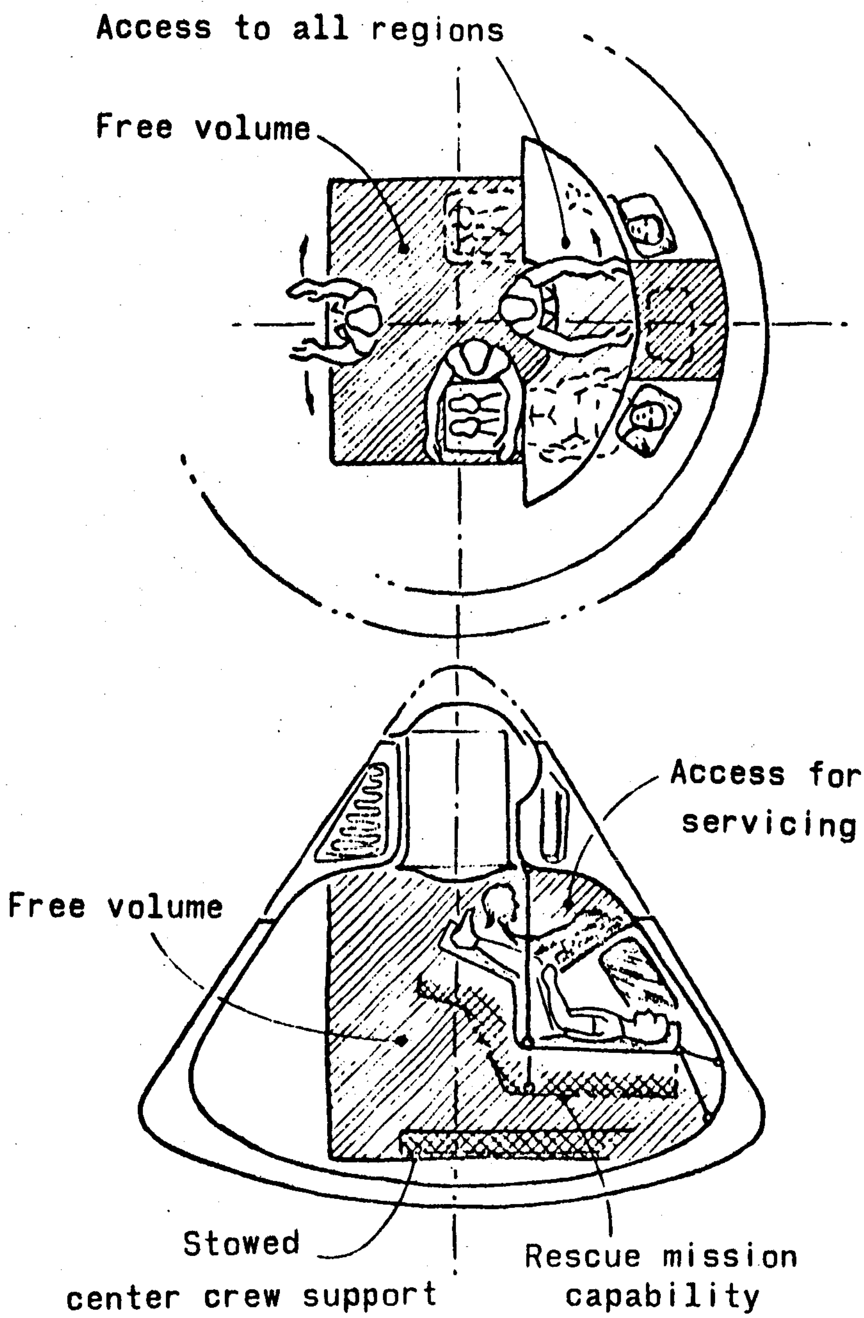


Figure 64.- Command module - Inboard profile,
volume utilization.

[redacted]

[redacted]

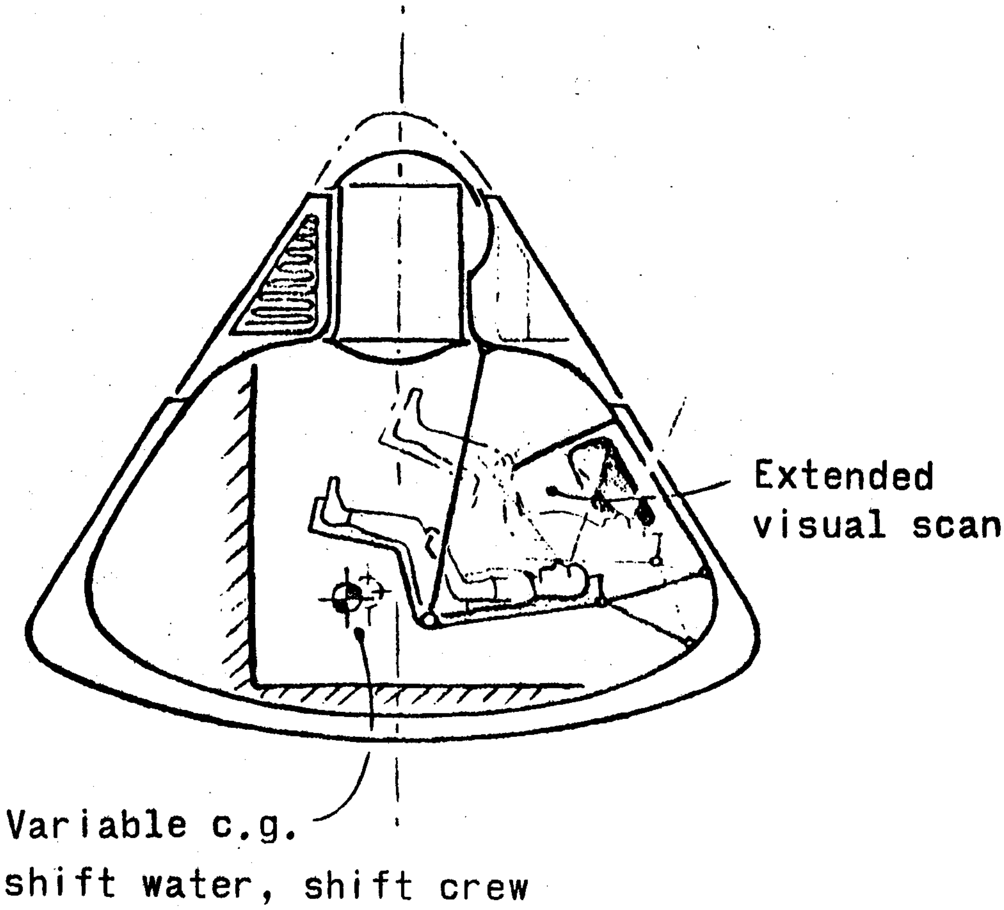


Figure 65.- Command module - Inboard profile, display coverage and center of gravity control.

[redacted]

[redacted]

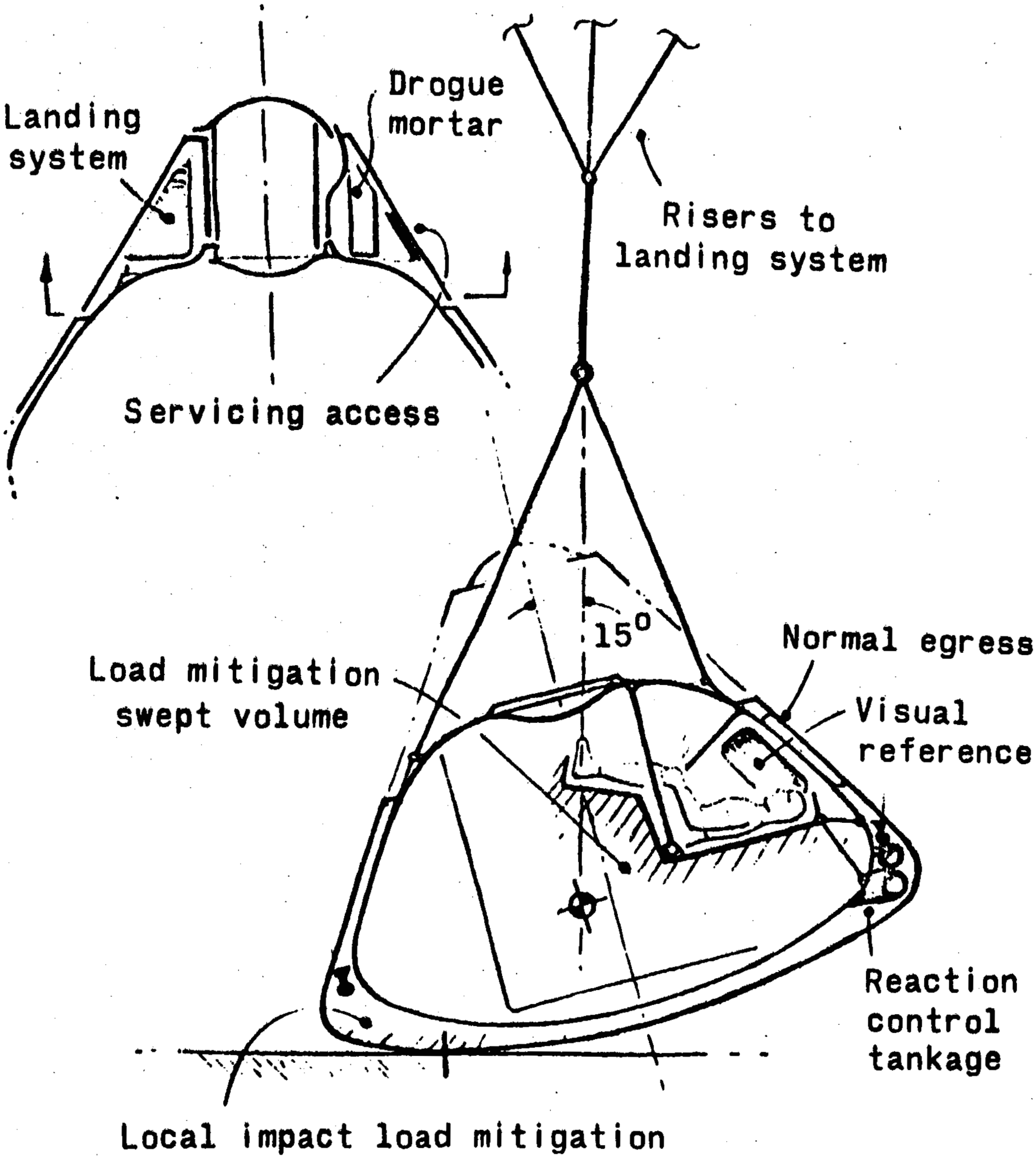
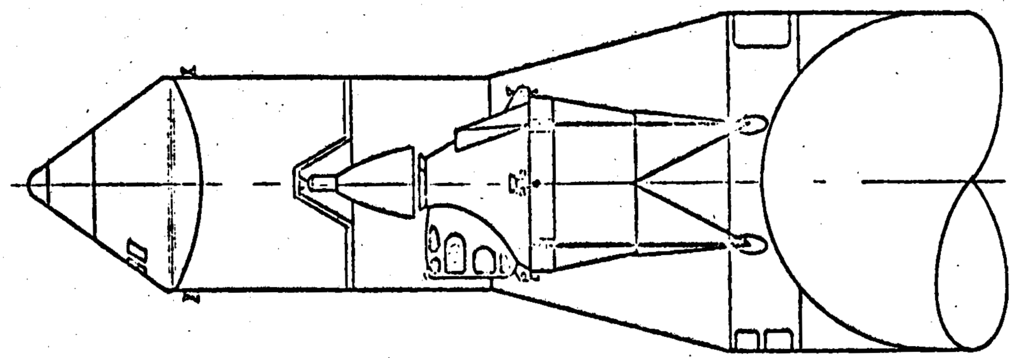


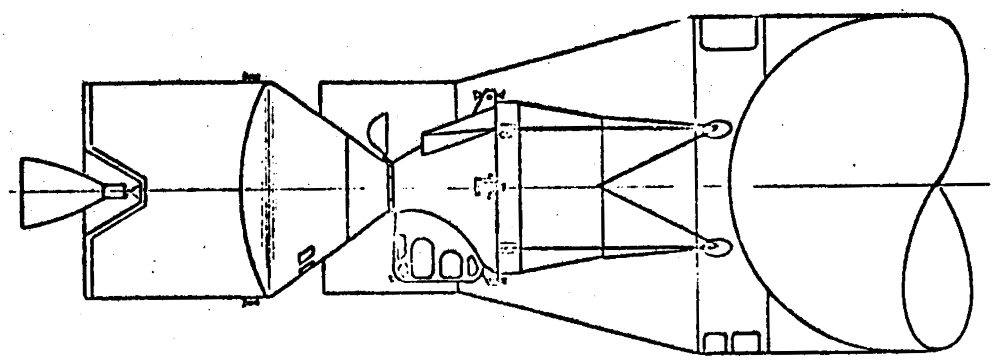
Figure 66.- Command module - Inboard profile, landing considerations.

[redacted]

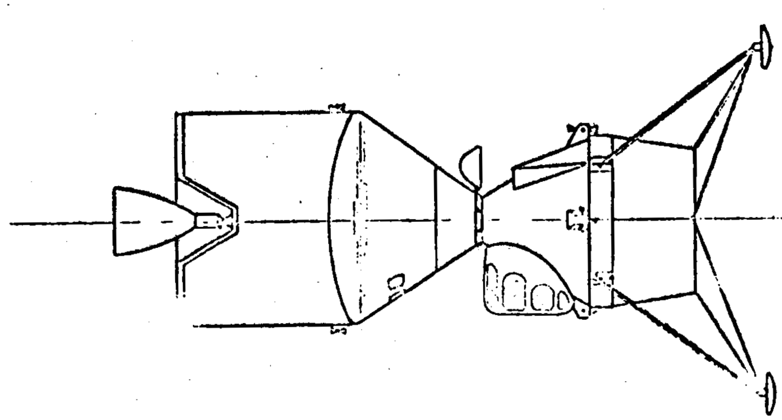
[redacted]



STOWED CONFIGURATION



INITIAL DOCKING CONFIGURATION



TRANSLUNAR CONFIGURATION

FIGURE 67. -
SPACECRAFT FLIGHT CONFIGURATIONS

[redacted]

[redacted]

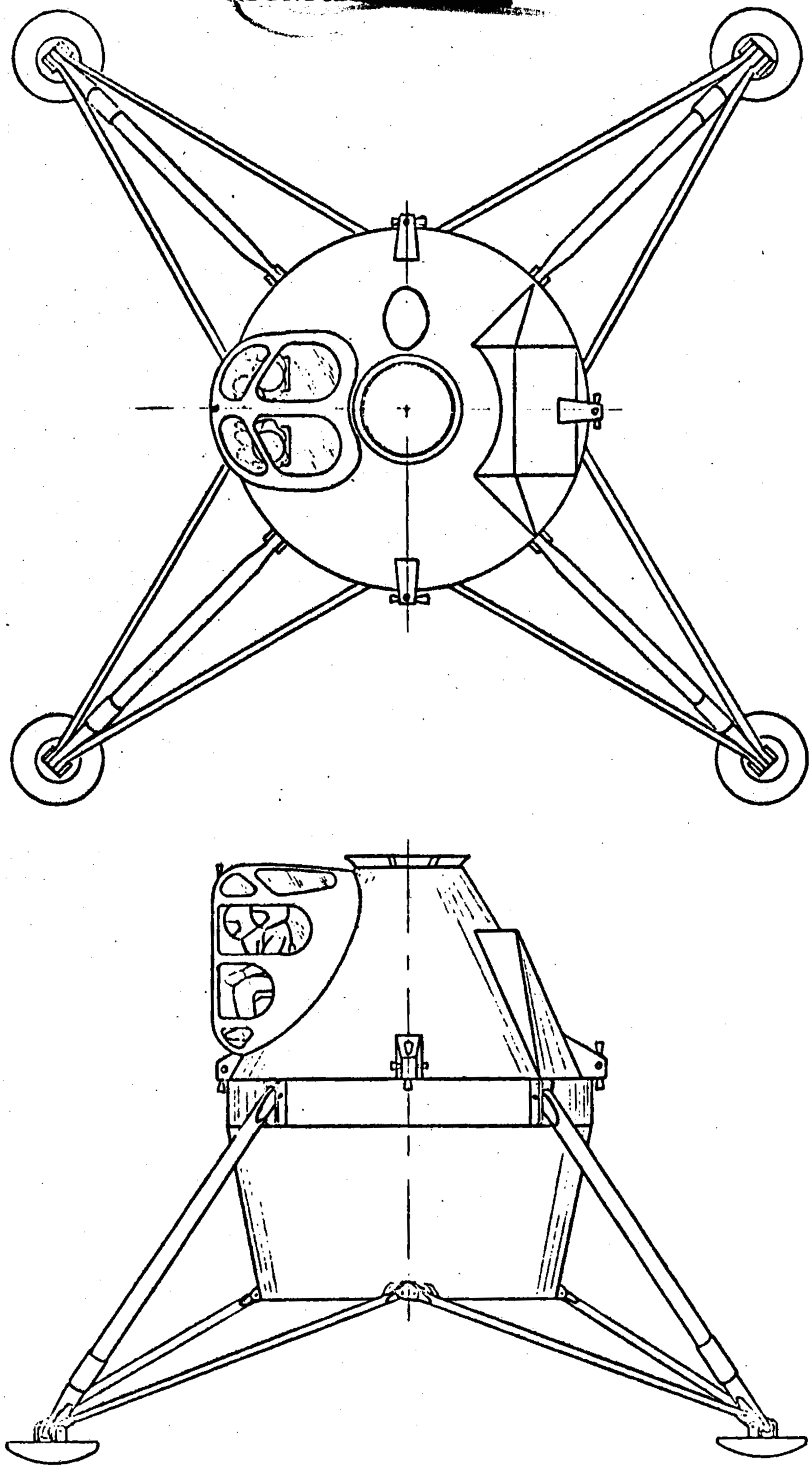


FIGURE 68. -
LUNAR EXCURSION MODULE EXTERNAL CONFIGURATION

[redacted]

[redacted]

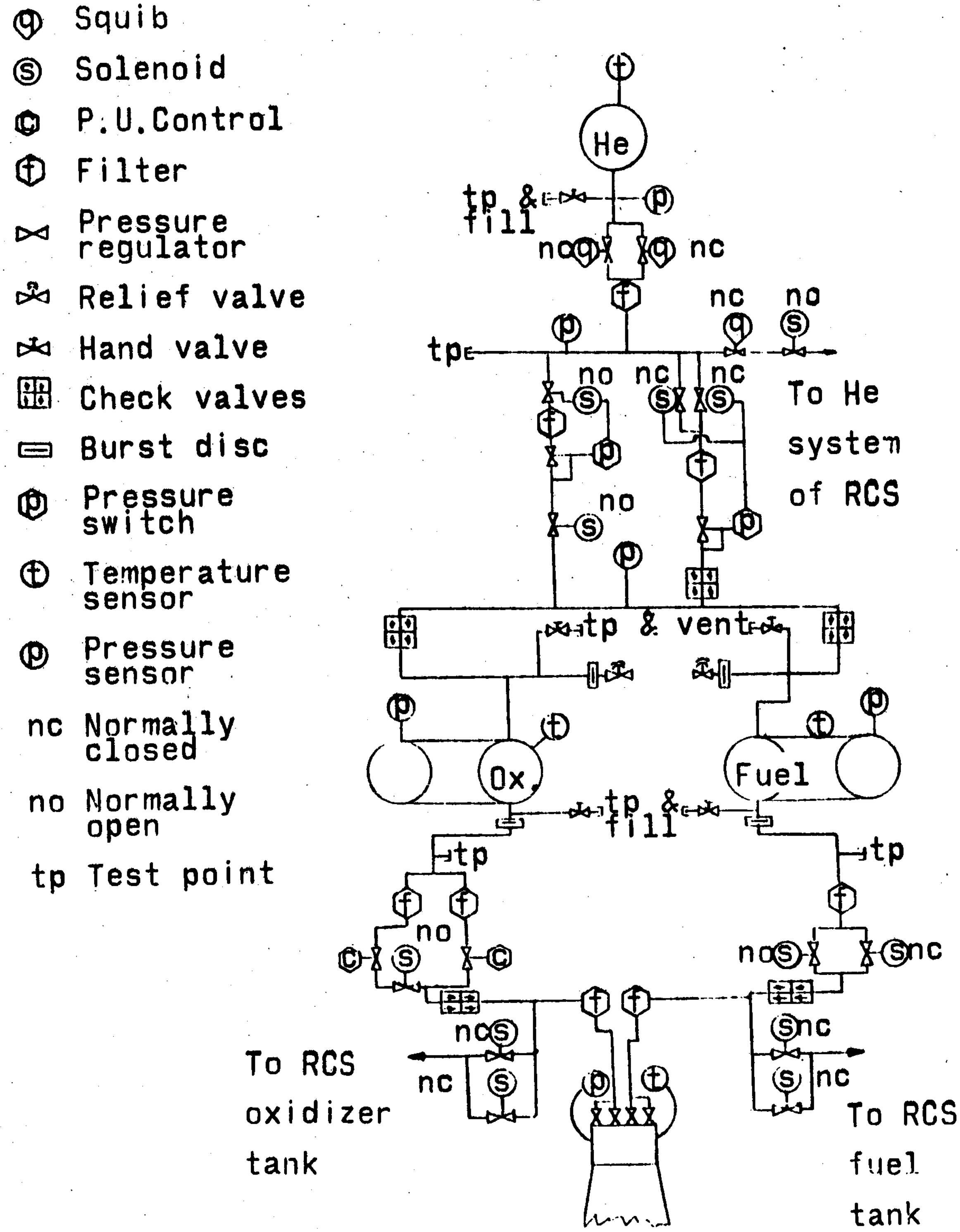


Figure 69.-Service propulsion system, Single chamber

[redacted]

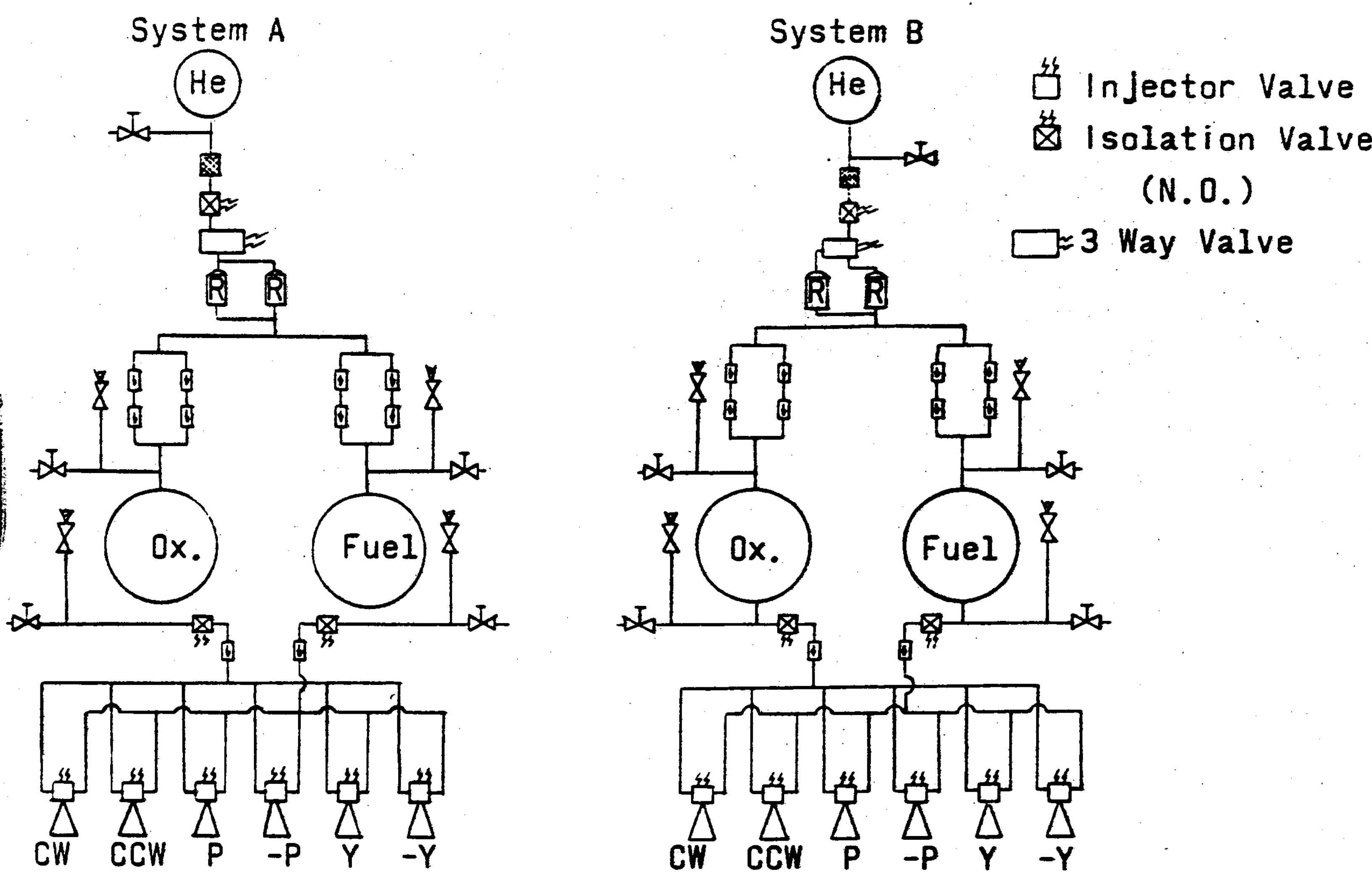


Figure 70.- Reaction control system, command module, schematic.

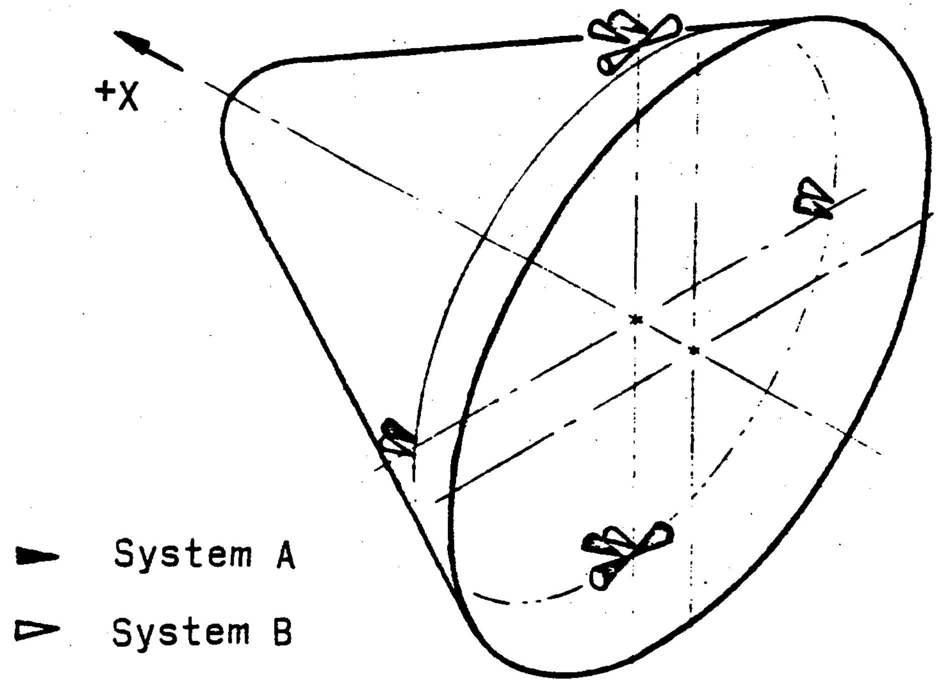


Figure 71.- Reaction control system - Command module - thrust chamber positions

[redacted]

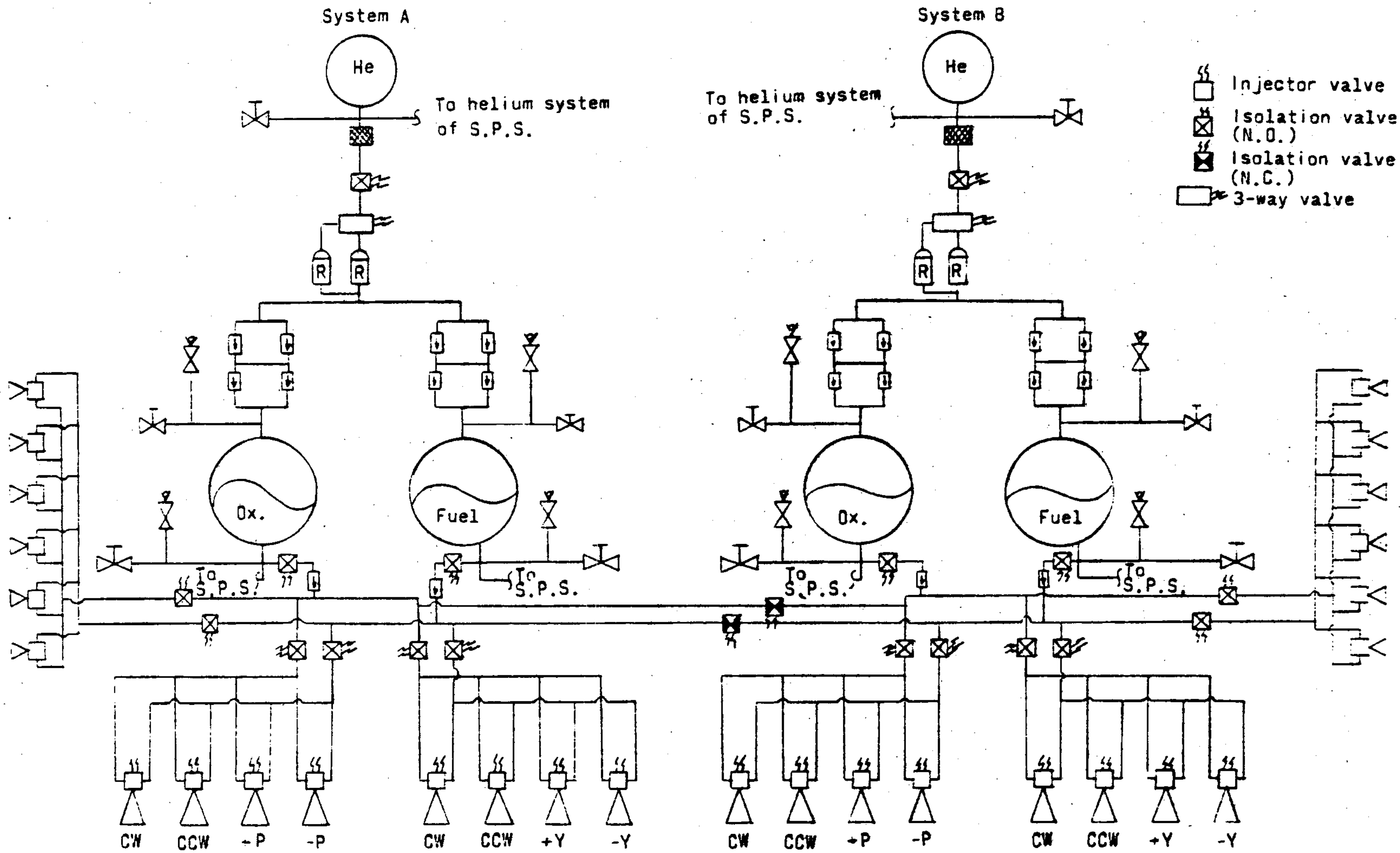


Figure 72.- Reaction control system, service module - schematic.

[redacted]

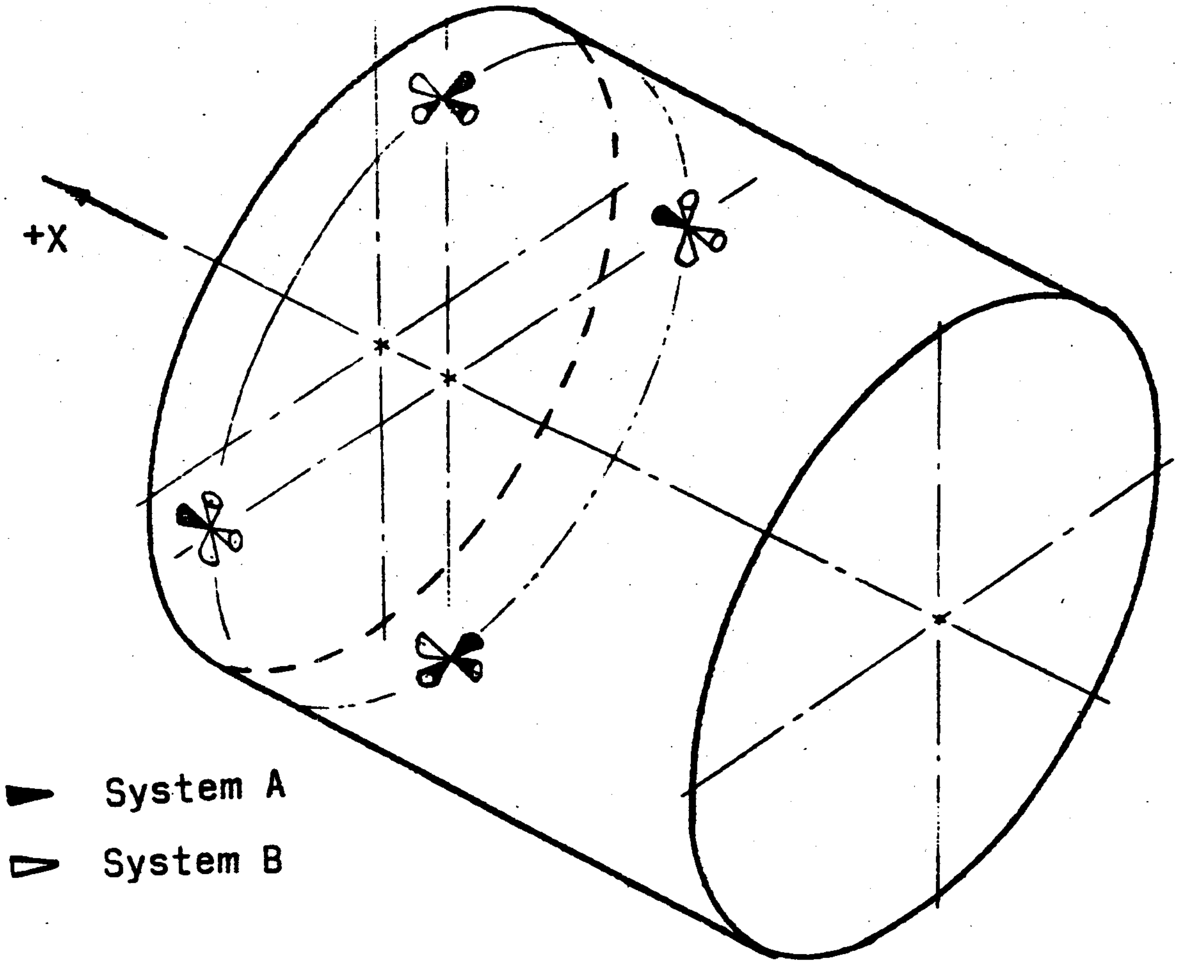
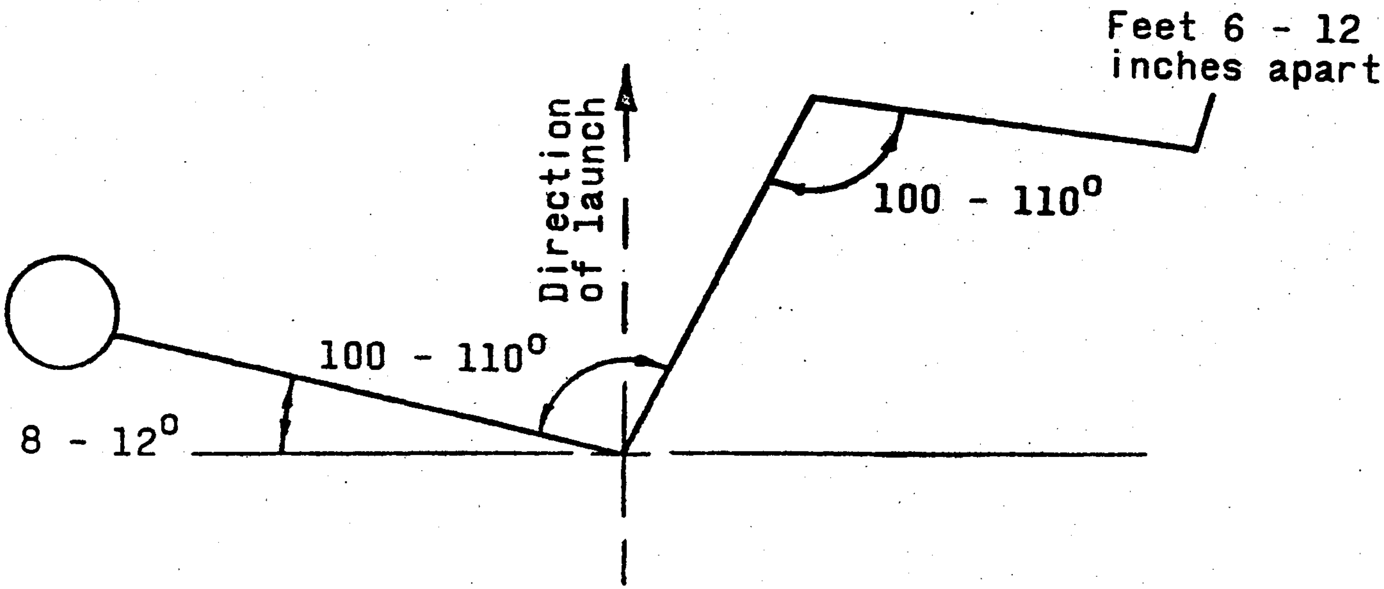


Figure 73.- Reaction control system, Service module, thrust chamber positions

[redacted]



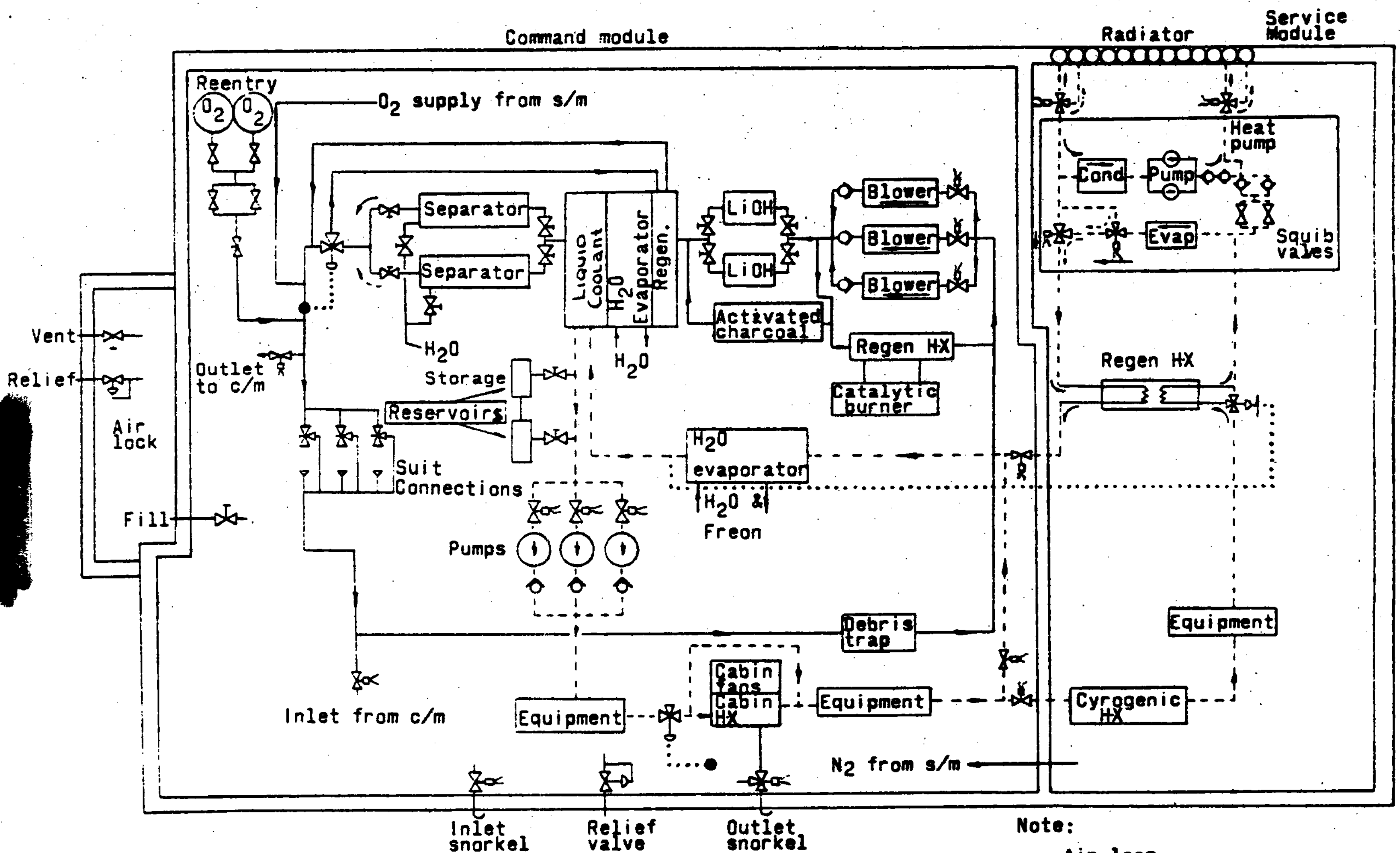
Upper arm parallel to trunk

elbow interior angle approximately 135°

Figure 74.- Body angles

[redacted]

[redacted]



Note:
Air loop ————
Liquid Coolant loop- - - - - -
Control·················

Figure 75.- Environmental control system.

[redacted]

[redacted]

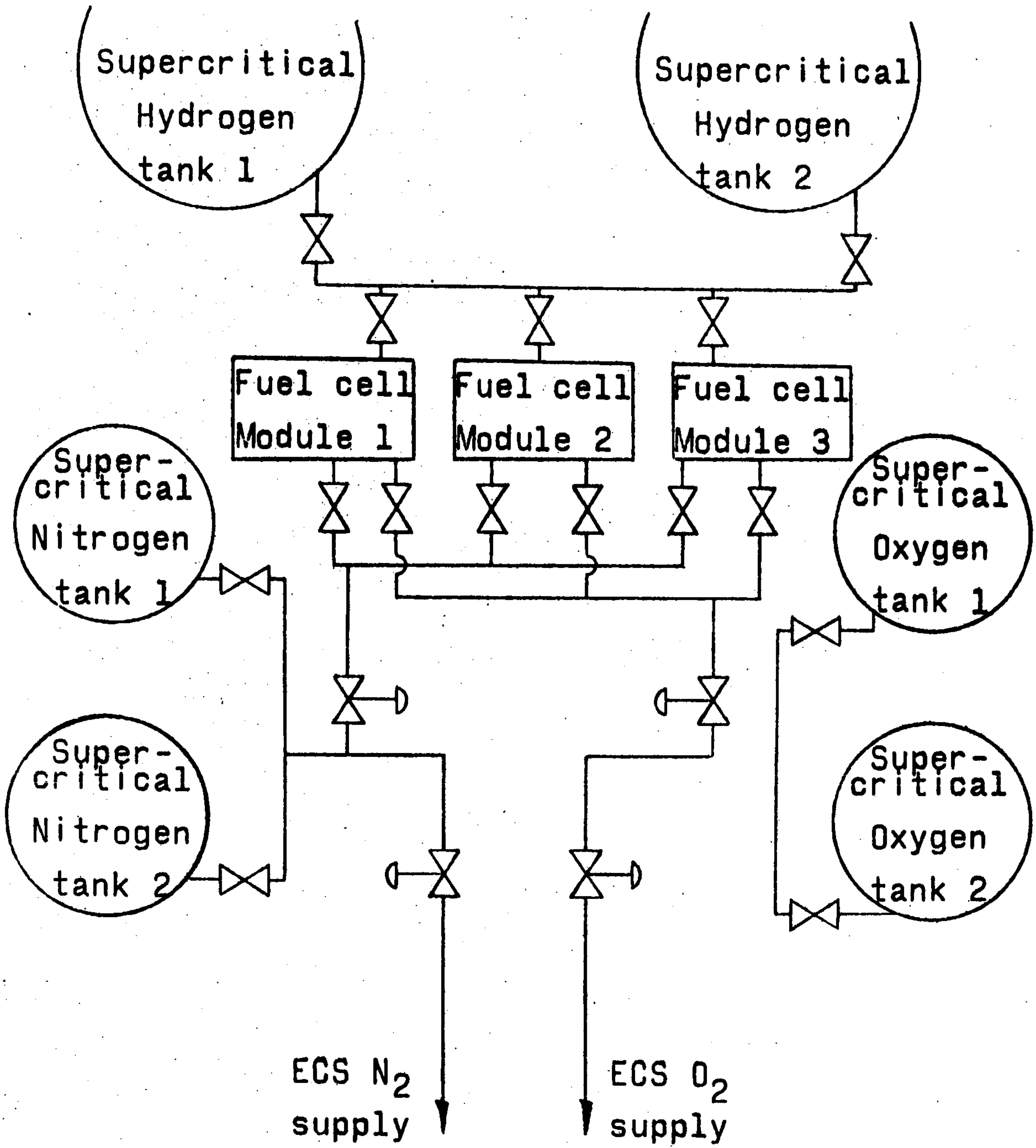


Figure 76.- Electrical power system - schematic.

[redacted]

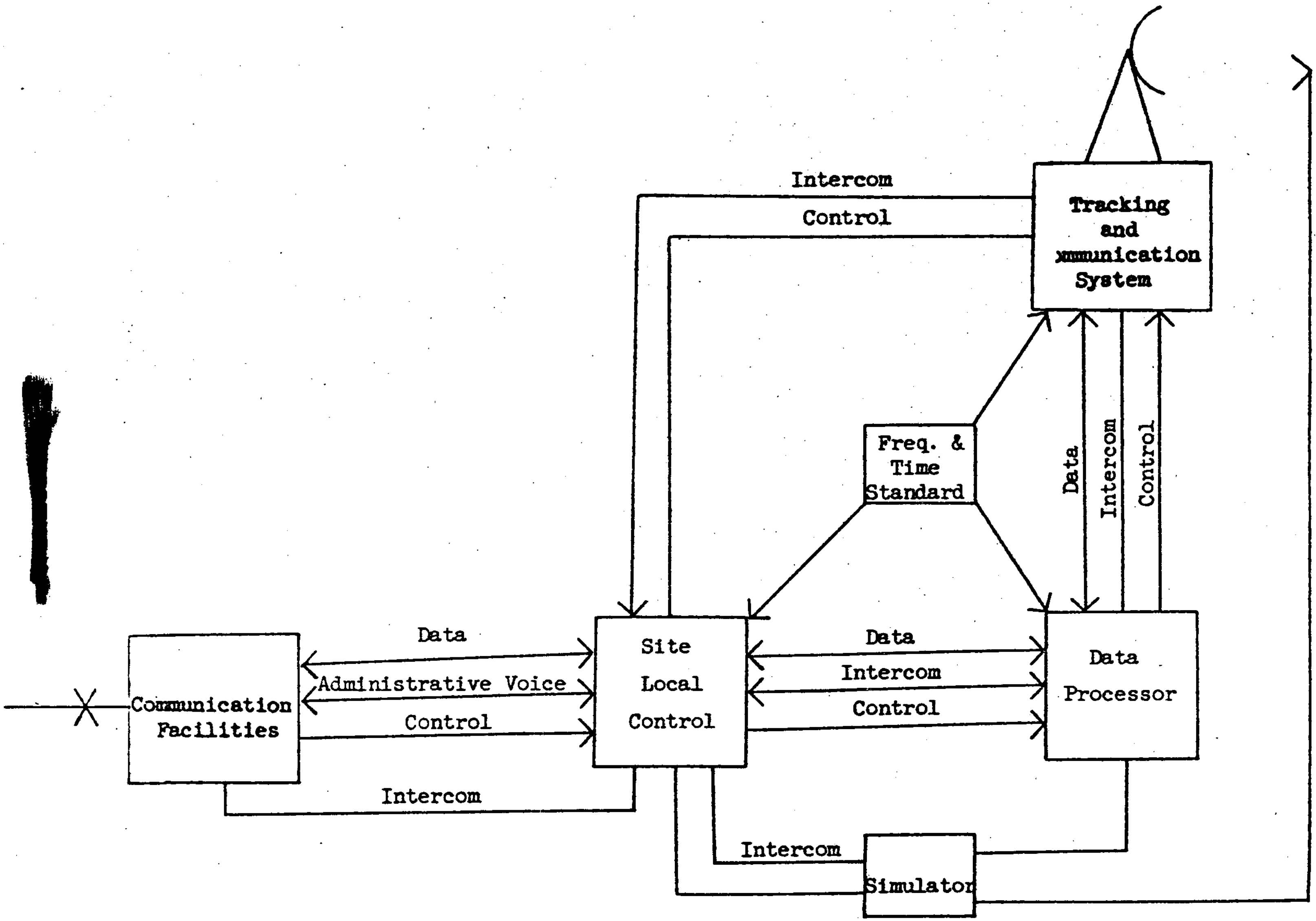


Figure 77.- Functional layout of GOSS station.

[redacted]

Data Lines
Tracking and Communications
Data Processor

Voice	⟷
TM (D)	⟶
TM (U)	⟵
Range	⟷
Range Rate	⟷
Azimuth	⟷
Elevation	⟷
Status	⟶

Data Processor - Local Control

Voice	⟷
TM (D)	⟶
TM (U)	⟵
Range	⟷
Range Rate	⟷
Azimuth	⟷
Elevation	⟷
Status	⟶

Local Control - Ground Communication Facility

Voice	⟷
TM (D)	⟶
TM (U)	⟵
Range	⟷
Range Rate	⟷
Azimuth	⟵
Elevation	⟵
Status	⟶

LEGEND

⟷ = Two Way Communication
⟶ = One Way Communication

Figure 78.- Data flow at GOSS station.

[redacted]

[redacted]

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